| AD NUMBER |
| --- |
| **AD872188** |
| LIMITATION CHANGES |
| TO:<br>**Approved for public release; distribution is unlimited.** |
| FROM:<br>**Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; 18 MAY 1970. Other requests shall be referred to Air Force Technical Applications Center, Attn: VSC, Alexandria, VA 23314. This document contains export-controlled technical data.** |
| AUTHORITY |
| **USAF ltr, 25 Jan 1972** |

(20)

# TECHNICAL REPORT NO. 70-16

# PRELIMINARY REPORT ON LONG-RANGE SEISMIC MEASUREMENTS PARTICIPATION IN PROJECT MIRACLE PLAY - HUMID WATER



TELEDYNE
GEOTECH

TECHNICAL REPORT NO. 70-16

# PRELIMINARY REPORT ON LONG-RANGE SEISMIC MEASUREMENTS PARTICIPATION IN PROJECT MIRACLE PLAY - HUMID WATER

by

Frank H. Johns

The research described in this report was authorized under Project VT/0703, Contract F33657-70-C-0646. This project is under the technical direction of the Air Force Technical Applications Center (AFTAC) and under the overall direction of Advanced Research Projects Agency (ARPA) under Project VELA-Uniform.



TELEDYNE GEOTECH
3401 Shiloh Road
Garland, Texas



18 May 1970

## IDENTIFICATION

| | |
|---|---|
| AFTAC Project No. | VT/0703 |
| Project Title: | Long-Range Seismic Measurements |
| ARPA Order No. | 624 |
| ARPA Code No. | 8F10 |
| Contractor: | Teledyne Geotech<br>Garland, Texas |
| Contract No. | F33657-70-C-0646 |
| Program Manager: | R. G. Reakes, 271-2561<br>Garland, Texas |

CONTENTS

## ILLUSTRATIONS

## ILLUSTRATIONS, Continued



* * * * * * * * *

## TABLES

## ABSTRACT

The HUMID WATER gas explosion, the second of a series of experiments called Project MIRACLE PLAY, was monitored by eight LRSM portable systems teams. The teams occupied the same sites that were occupied for the DIODE TUBE explosion. Visual analysis of the seismograms shows that the STERLING, DIODE TUBE, and HUMID WATER signals were recorded at Lucedale, Mississippi (LD-MS). Spectra of the signals at LD-MS show that the power level of HUMID WATER was greater than that of STERLING.

# PRELIMINARY REPORT ON LONG-RANGE SEISMIC MEASUREMENTS PARTICIPATION IN PROJECT MIRACLE PLAY - HUMID WATER

## 1. INTRODUCTION

The Long-Range Seismic Measurements (LRSM) Program was assigned the task of operating eight portable seismograph systems during Project MIRACLE PLAY. This project was undertaken as part of the VELA-Uniform research program. The Project MIRACLE PLAY tests are being conducted to develop methods of improving detection, identification, and location of underground nuclear explosions. The project will involve three gas detonations in the Tatum Salt Dome in Mississippi. The first shot, DIODE TUBE, was detonated on 2 February 1969; the second shot, HUMID WATER, was detonated on 19 April 1970; and the third shot, DINAR COIN, is scheduled later in the year.

The participation of these systems, the data reduction effort, and the preparation of a report are authorized under Project VT/0703, Contract F33657-70-C-0646. This project is under the technical direction of the Air Force Technical Applications Center (AFTAC) and under the overall direction of the Advanced Research Projects Agency (ARPA).

## 2. SHOT DATA

The Tatum Salt Dome is located in Lamar County, Mississippi, about seven miles west of Purvis. On 19 April 1970, an oxygen and methane gas mixture, having an energy yield equivalent to 315 tons of TNT, was detonated 2,700 feet underground in a spherical cavity, 110 feet in diameter, within the Salt Dome. The detonation was premature and triggered by external forces, and it is believed that lightning was the mechanism that triggered the explosion. The original cavity was created by a 5-kiloton nuclear device, which was detonated on 22 October 1964 as a part of Project SALMON and the DIODE TUBE shot, a gas mixture, detonated on 2 February 1969, having an energy yield equivalent of 315 tons of TNT.

## 3. LRSM SITE INFORMATION

The sites occupied by LRSM teams for Project MIRACLE PLAY are shown in figure 1. Eight LRSM portable systems were used in this project. Four systems were placed in a ring around the shot point, with a radius of about 68 km; and, except for the site at Picayune, site locations were identical to those occupied for STERLING. The new Picayune site was moved 50 feet north of the former site location because of flooding in the immediate area. These four portable system sites were designated: Laurel, Mississippi (LL-MS); Lucedale, Mississippi (LD-MS); Picayune, Mississippi (PC-MS); and McComb, Mississippi (MB-MS). The remaining four sites encircled LD-MS and were designated Lumberton, Mississippi (LU-MS); Richton, Mississippi (RI-MS); and Lucedale, Mississippi (LD2MS and LD3MS). Reasons for this deployment were: (1) to duplicate STERLING and DIODE TUBE, and (2) to investigate the STERLING amplitude anomaly at LD-MS.

The table in figure 1 gives a general summary of site information. Detailed descriptions of the geology underlying each site are given in Appendix 1. All of the LRSM teams operated 3-component short-period and long-period seismograph systems; responses of the short-period seismographs are shown in figure 2. The portable systems recorded all data on magnetic tape using a slow-speed (0.03 ips) tape recorder.

## 4. DATA PRESENTATION

### 4.1 SEISMOGRAMS

Seismograms of the short-period data recorded from HUMID WATER at six of the LRSM sites discussed above are included in Appendix 2. No data were available from LU-MS or PC-MS due to maintenance being performed on the systems. The playouts show the signal or the period of time during which the signal was expected. No long-period data recordings from STERLING, DIODE TUBE, or HUMID WATER are presented in this report.

Playouts of the HUMID WATER long-period data were analyzed and no signal was apparent; therefore, seismograms of the long-period data were not included in this report.

The data were reproduced from magnetic tape at various attenuation levels to optimize the trace amplitudes for analysis purposes. Accordingly, traces are in some cases shown at magnifications that do not correspond or relate to the nominal operating magnifications at that particular site.

The information appearing on the seismograms in the appendices is interpreted as follows:

a. Site Designator (e.g. - LD-MS): Figure 1 gives full information on the names and locations of the sites;

b. Trace Identification (e.g. - SPR): BCD - Binary Coded Decimal timing trace output by the portable systems' Geotech Model 19000 timing system.

Station Timing - Timing program output by the portable observatories' Geotech Model 19000 timing systems, consisting basically of a pulse every ten seconds, omitted on the minute. This program is superimposed on all the data traces during playout.

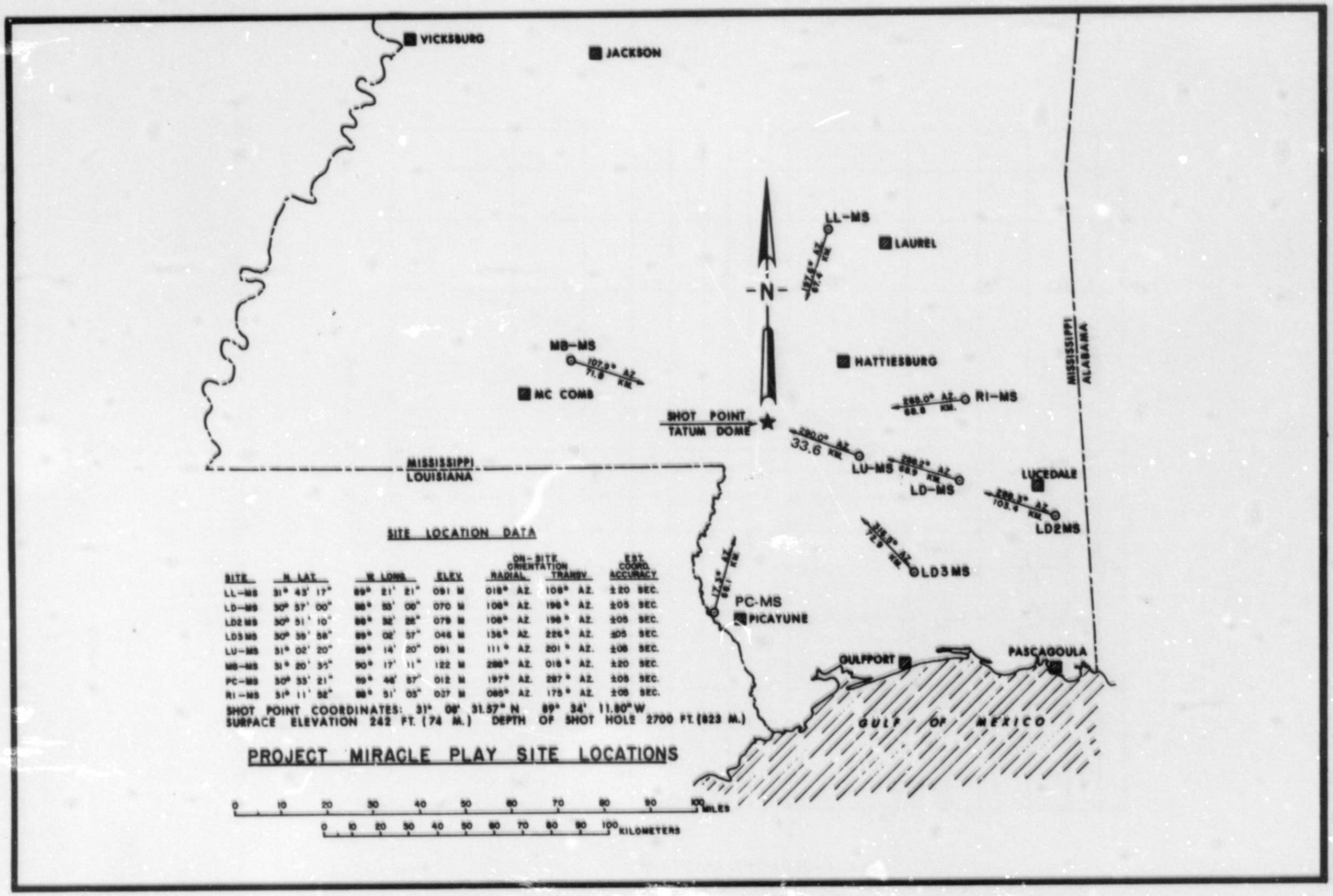



Figure 1. Site location map

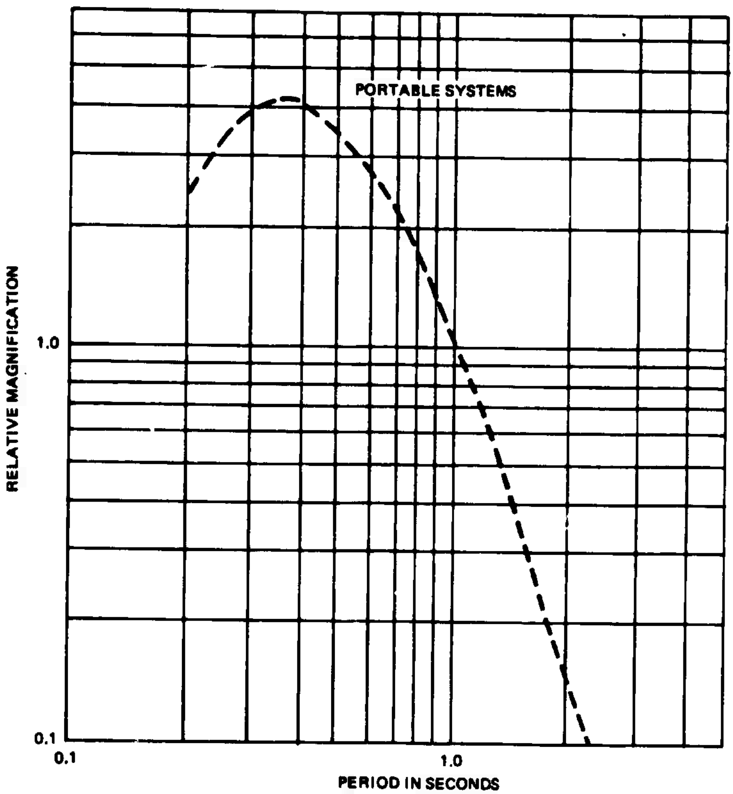



Figure 2. Frequency response of the LRSM short-period seismographs

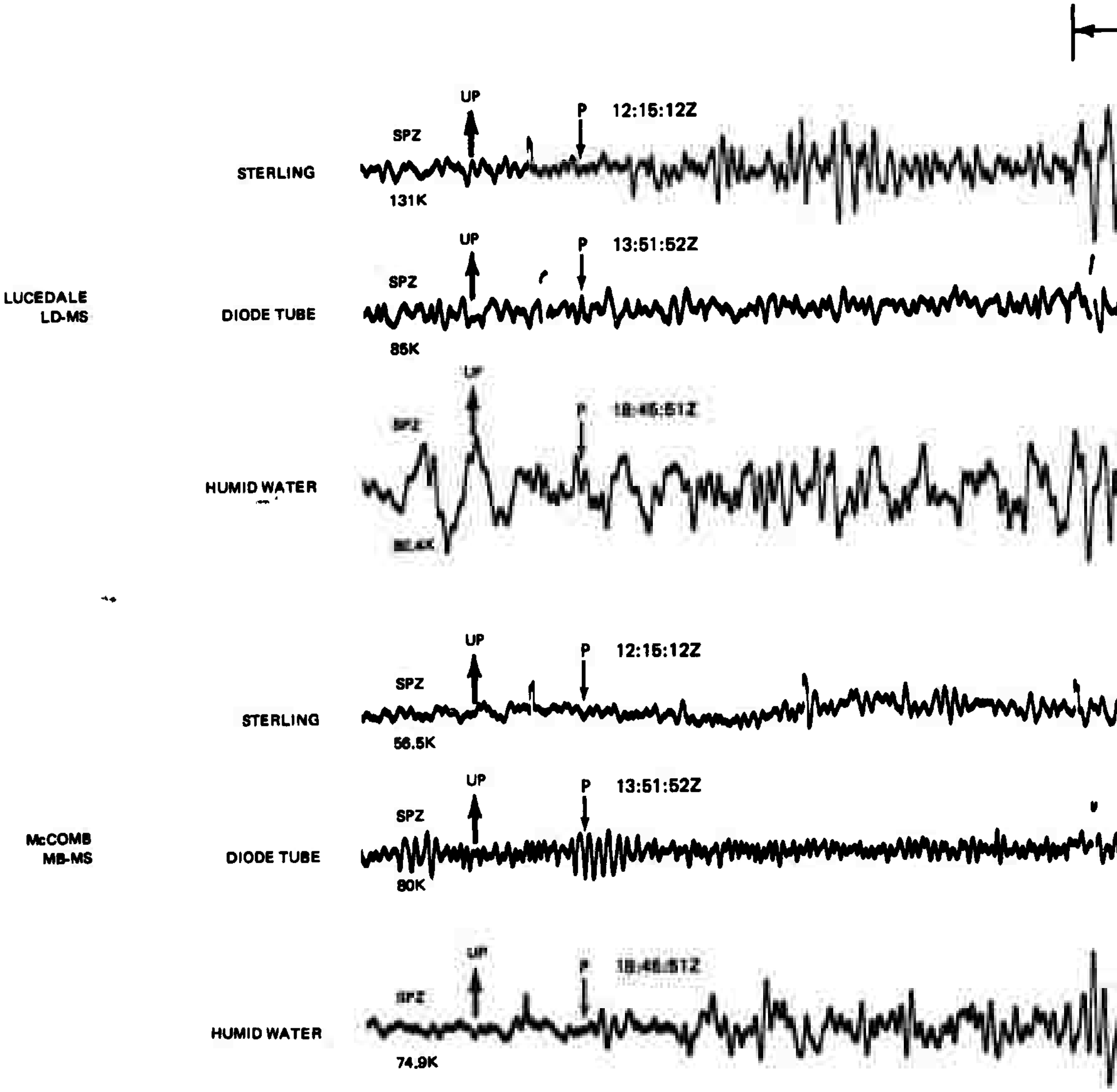
| | |
|---|---|
| SPZ - | Short-period vertical seismograph. Upward movement of earth produces upward movement of trace, as shown by arrow. |
| SPR - | Short-period radial seismograph. Oriented for maximum sensitivity along line to shot point. Movement of earth toward azimuth, indicated by arrow, produces upward deflection on film. |
| SPT - | Short-period transverse seismograph. Oriented for maximum sensitivity along line orthogonal to direction to shot point. Movement of earth toward azimuth, indicated by arrow, produces upward deflection on film. |
| WWV - | Radio time program broadcast by the National Bureau of Standards' Radio Station WWV. |

c. Trace Magnification (e.g. - 138K): Given in thousands (K) at a frequency of 1.0 cps. See response curve in figure 2 to compute magnifications at other frequencies.

d. Time (e.g. - 18:46:00.0): Identifies a particular 10-second pulse according to Greenwich Mean (or Zulu) Time.

## 4.2 SEISMOGRAM COMPARISONS

Figures 3, 4, and 5 display a comparison of STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on vertical, radial, and transverse seismographs, respectively, at Lucedale (LD-MS) and McComb (MB-MS). Figures 6, 7, and 8 display a comparison of DIODE TUBE and HUMID WATER seismograms recorded on vertical, radial, and transverse seismographs, respectively, at Richton (RI-MS), Lucedale (LD2MS), and Lucedale (LD3MS). These three sites were not activated for the STERLING event. Figures 9, 10, and 11 display a comparison of the STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on vertical, radial, and transverse seismographs at Laurel (LL-MS). Also shown is a comparison of STERLING and DIODE TUBE seismograms recorded on vertical, radial, and transverse seismographs at Picayune (PC-MS). No data were recorded during the HUMID WATER event at PC-MS. DIODE TUBE seismograms recorded on the vertical, radial, and transverse seismographs at Lumberton (LU-MS) are also displayed. The site was not activated for the STERLING event and no data were recorded during the HUMID WATER event. Seismograms are aligned with respect to estimated arrival times of P derived from the Jeffreys-Bullen seismological tables. The following origin times were used: 12:15:00Z, 3 December 1966 for STERLING; 13:51:39.47Z, 2 February 1969 for DIODE TUBE; and 18:45:38.4Z, 19 April 1970 for HUMID WATER. The HUMID WATER origin time is an estimate since the event detonated prematurely. There is no visible P phase; therefore, computed travel times could not be used to arrive at an origin time. However, by comparing the



LUCEDALE
LD-MS
STERLING
SPZ
UP
P
12:15:12Z
131K
DIODE TUBE
SPZ
UP
P
13:51:52Z
85K
HUMID WATER
UP
P
McCOMB
MB-MS
STERLING
SPZ
UP
P
12:15:12Z
56.5K
DIODE TUBE
SPZ
UP
P
13:51:52Z
80K
HUMID WATER
UP
P
74.9K

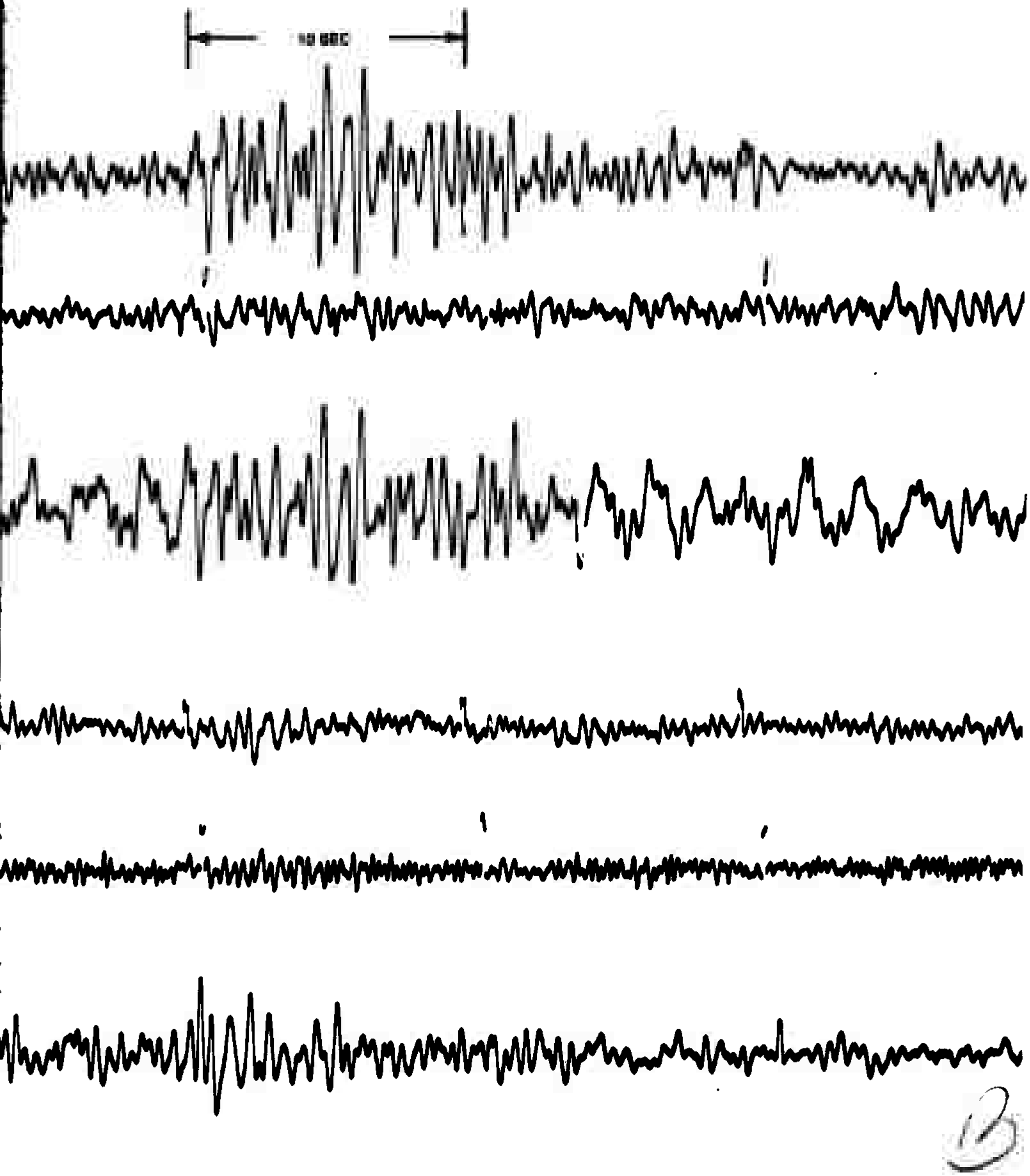
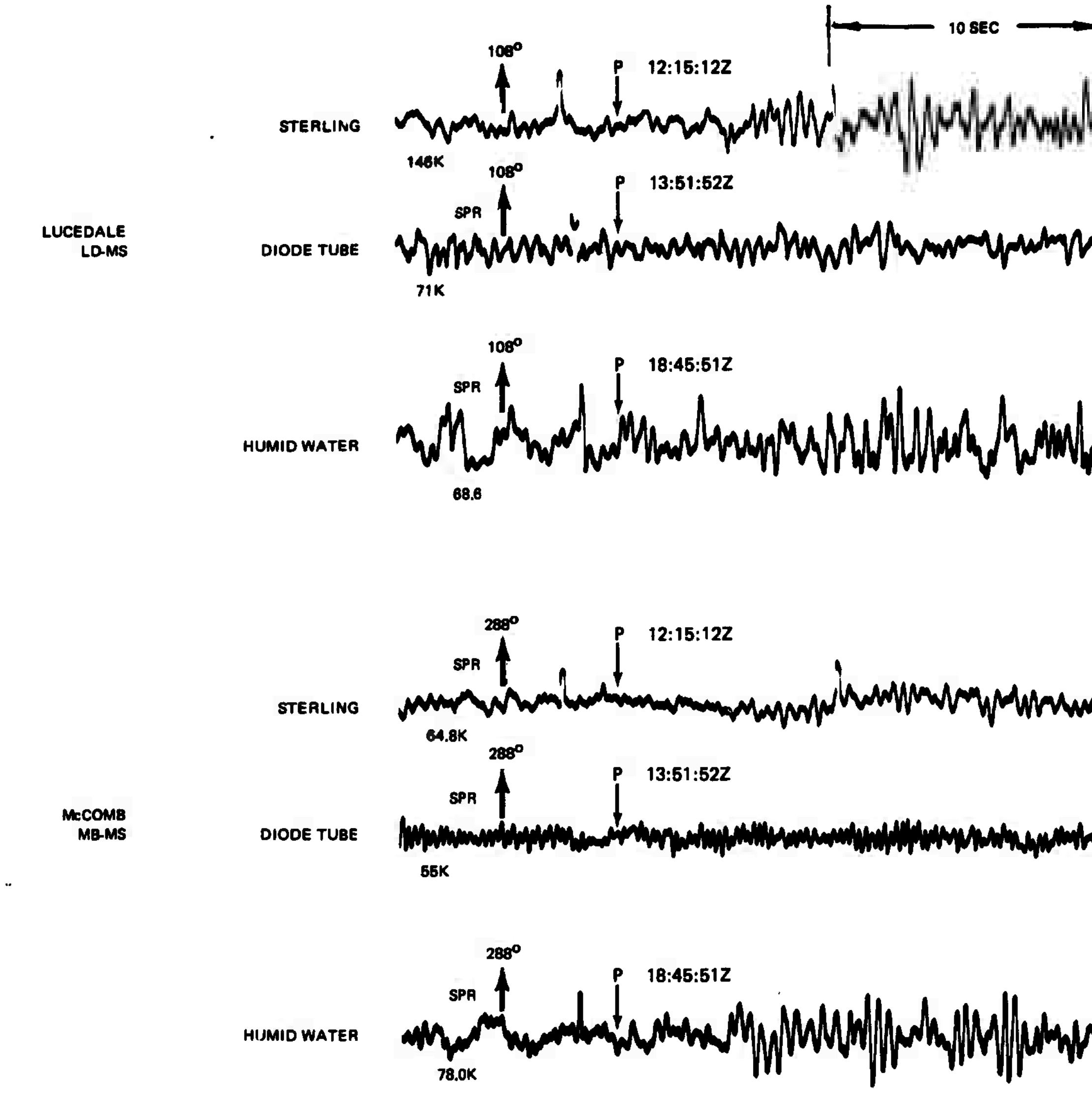
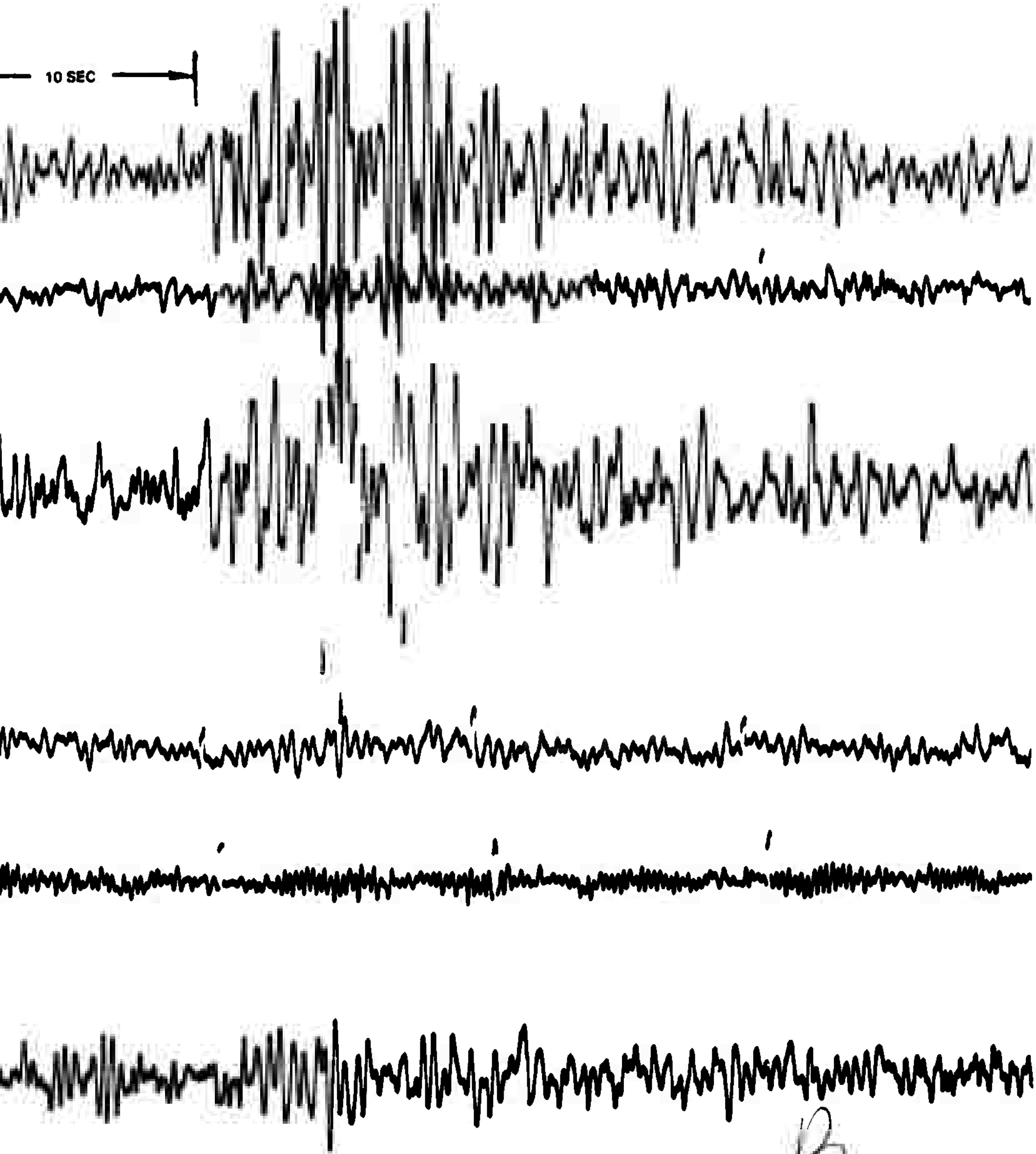


Figure 3. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on vertical seismographs at LD-MS and MB-MS. Seismograms are aligned with respect to the calculated arrival times of P.

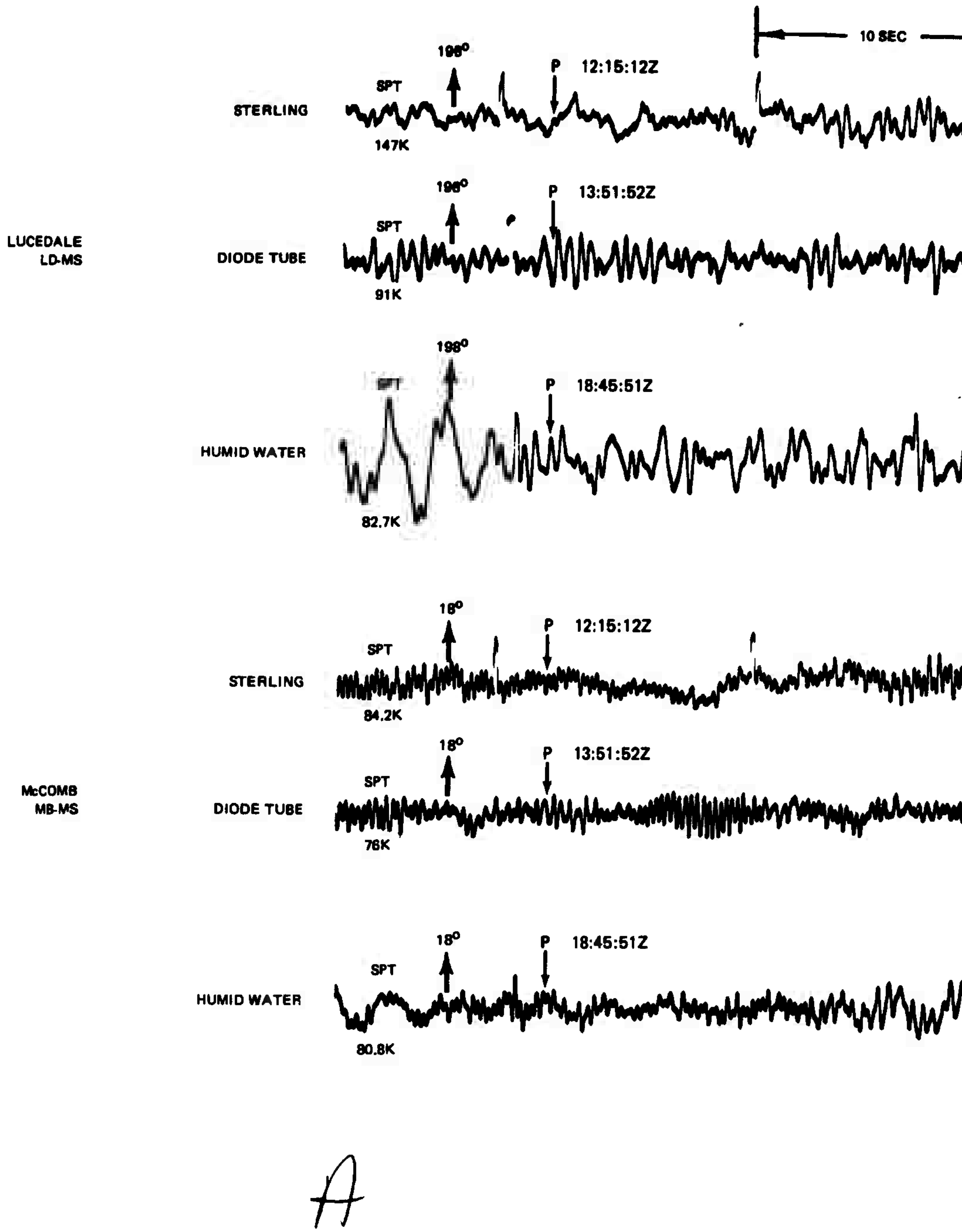


10 SEC
LUCEDALE
LD-MS
STERLING
108°
P
12:15:12Z
146K
DIODE TUBE
108°
SPR
P
13:51:52Z
71K
HUMID WATER
108°
SPR
P
18:45:51Z
68.6
McCOMB
MB-MS
STERLING
288°
SPR
P
12:15:12Z
64.8K
DIODE TUBE
288°
SPR
P
13:51:52Z
55K
HUMID WATER
288°
SPR
P
18:45:51Z
78.0K




B

Figure 4. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on radial seismographs at LD-MS and MB-MS. Seismograms are aligned with respect to the calculated arrival times of P.


10 SEC
LUCEDALE
LD-MS
STERLING
SPT
198°
P
12:15:12Z
147K
DIODE TUBE
13:51:52Z
91K
HUMID WATER
18:45:51Z
82.7K
McCOMB
MB-MS
18°
84.2K
76K
80.8K
A

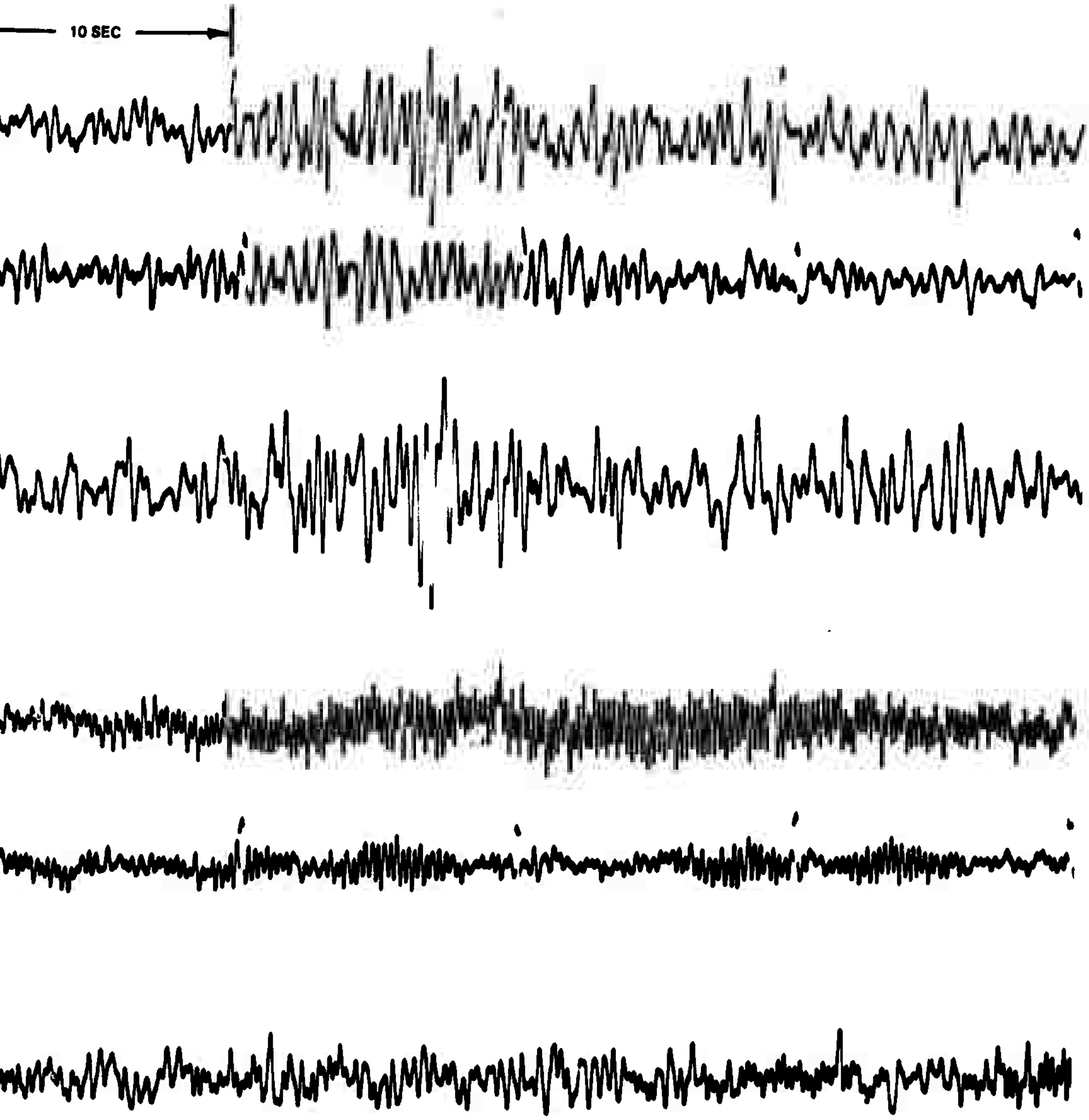
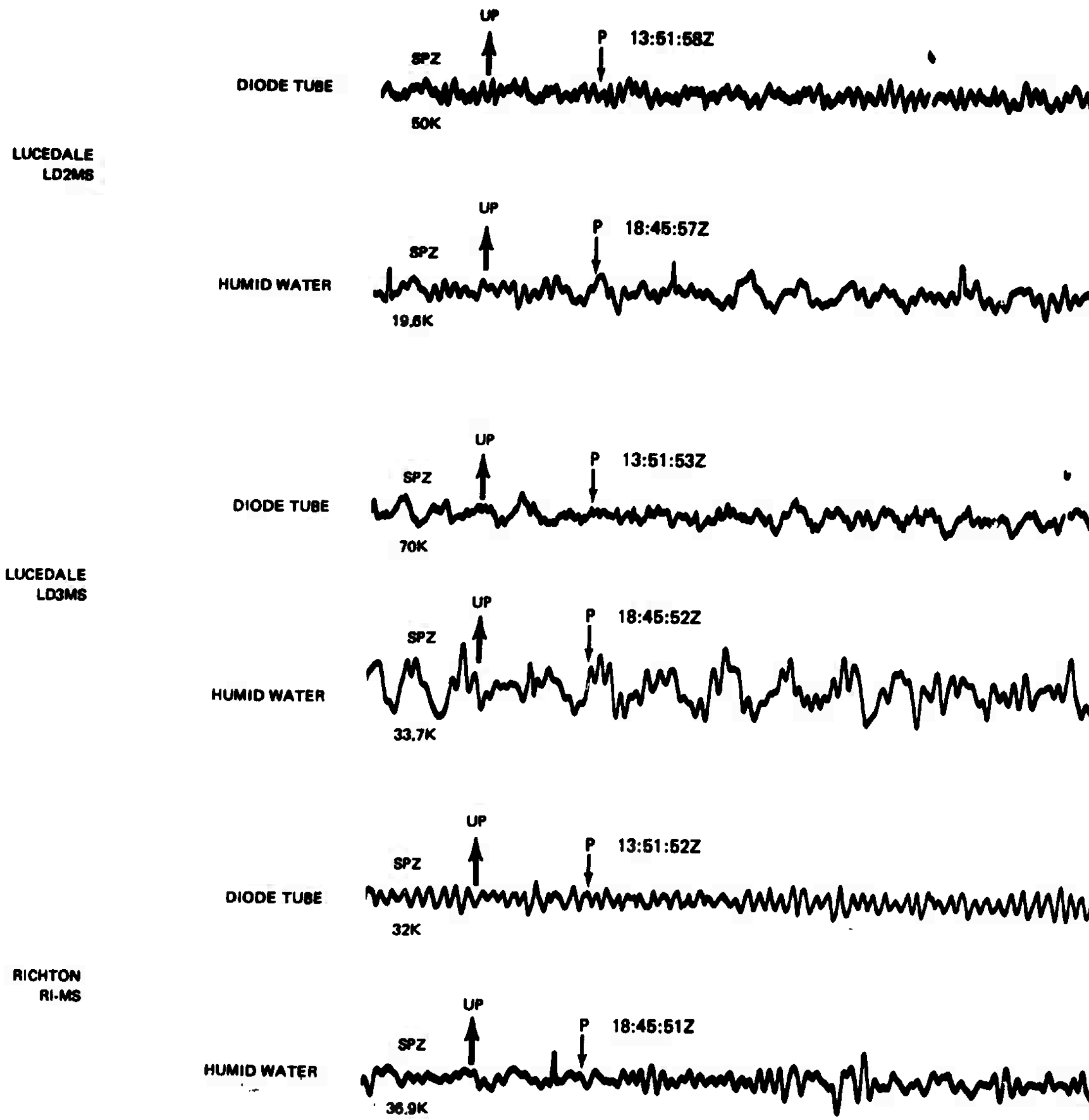



Figure 5. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on transverse seismographs at LD-MS and MB-MS. Seismograms are aligned with respect to the calculated arrival times of P.



B


UP
P 13:51:58Z
SPZ
DIODE TUBE
50K
LUCEDALE
LD2MS
UP
P 18:45:57Z
SPZ
HUMID WATER
19.6K
UP
P 13:51:53Z
SPZ
DIODE TUBE
70K
LUCEDALE
LD3MS
UP
P 18:45:52Z
SPZ
HUMID WATER
33.7K
UP
P 13:51:52Z
SPZ
DIODE TUBE
32K
RICHTON
RI-MS
UP
P 18:45:51Z
SPZ
HUMID WATER
36.9K

A

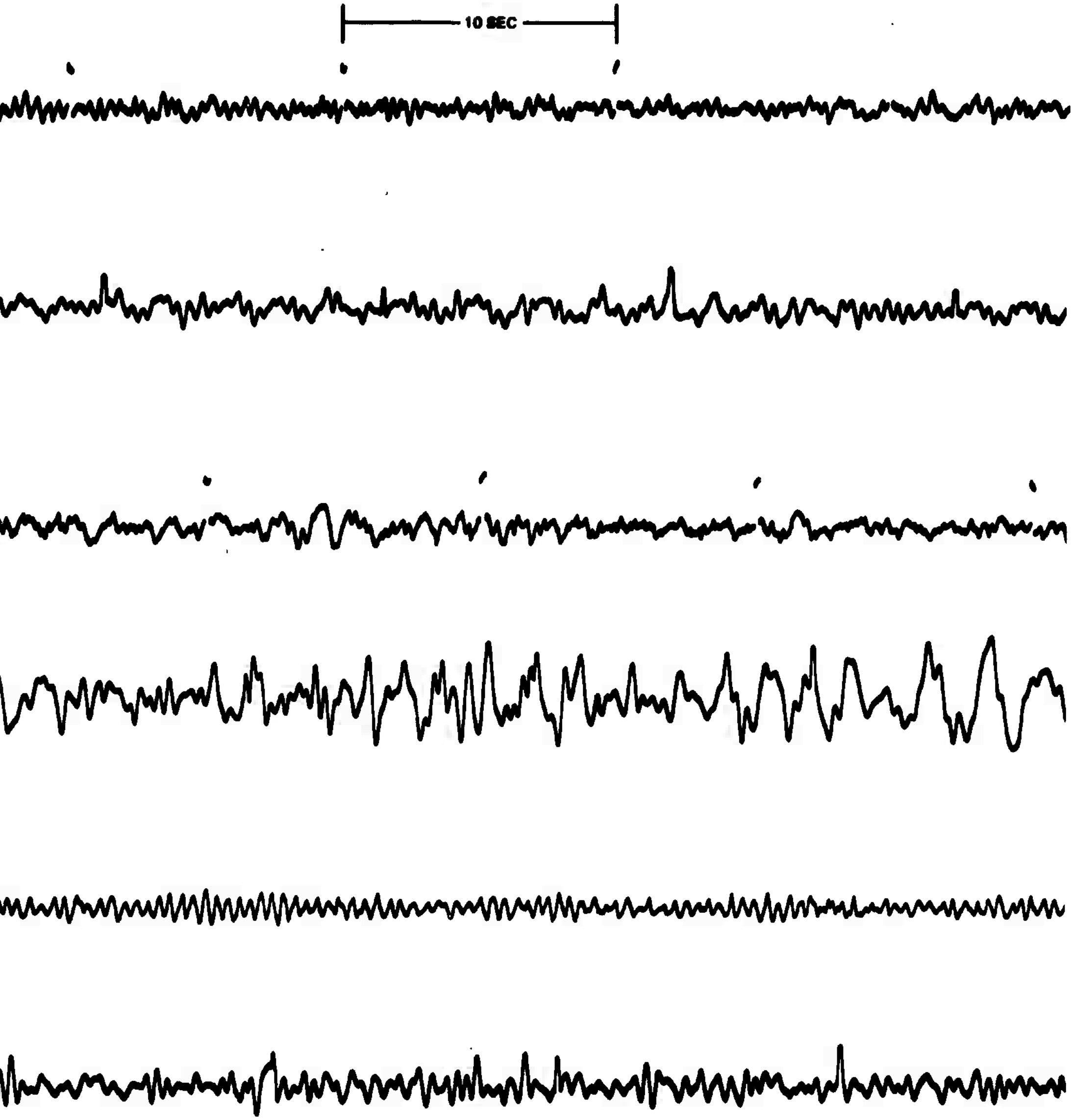
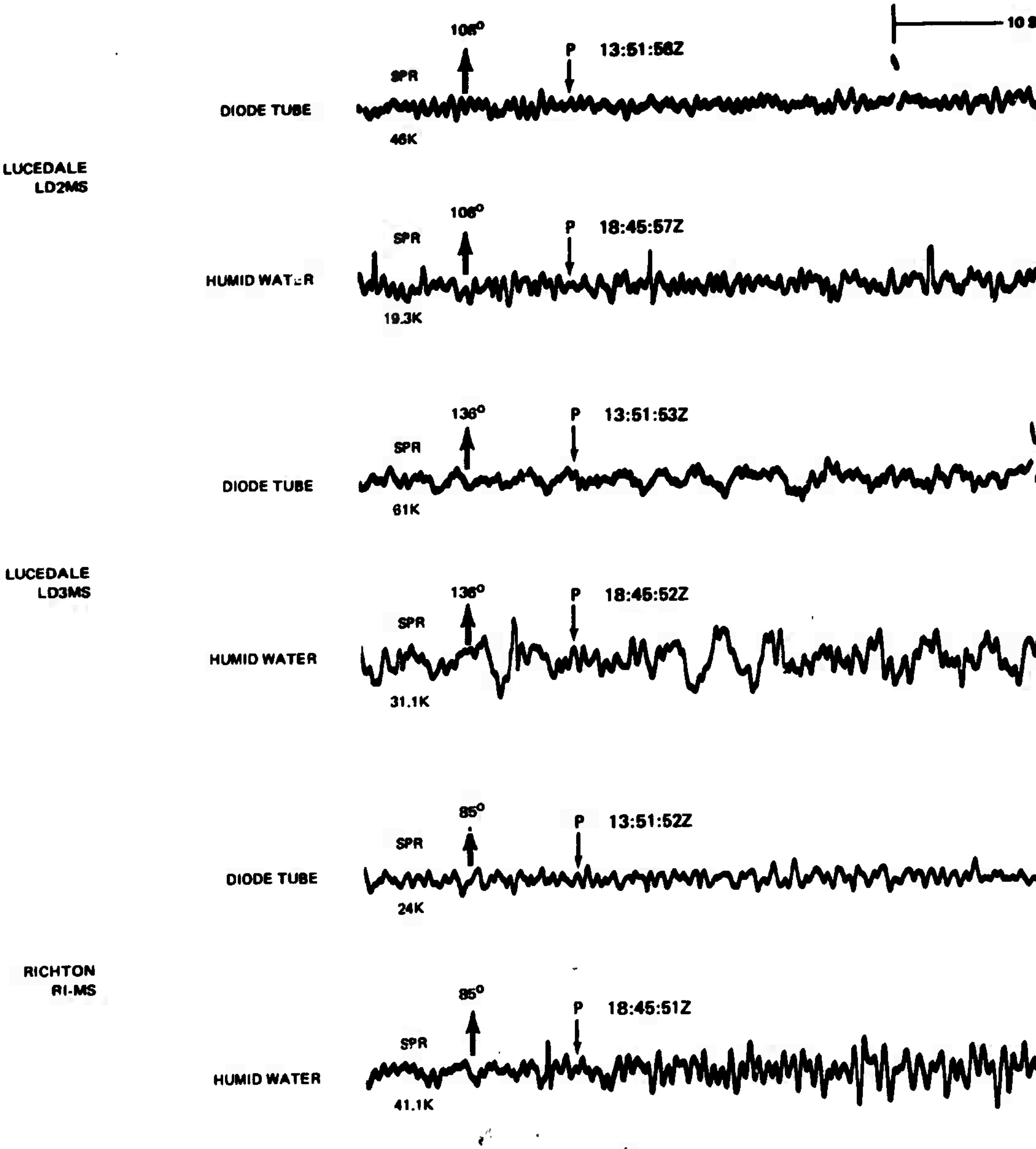



Figure 6. DIODE TUBE and HUMID WATER seismograms recorded on vertical seismographs at LD2MS, LD3MS, and RI-MS. Seismograms are aligned with respect to the calculated arrival times of P.



B


LUCEDALE
LD2MS
DIODE TUBE
SPR
106°
P 13:51:56Z
46K
HUMID WATER
SPR
106°
P 18:45:57Z
19.3K
LUCEDALE
LD3MS
DIODE TUBE
SPR
136°
P 13:51:53Z
61K
HUMID WATER
SPR
136°
P 18:45:52Z
31.1K
RICHTON
RI-MS
DIODE TUBE
SPR
85°
P 13:51:52Z
24K
HUMID WATER
SPR
85°
P 18:45:51Z
41.1K
10

A

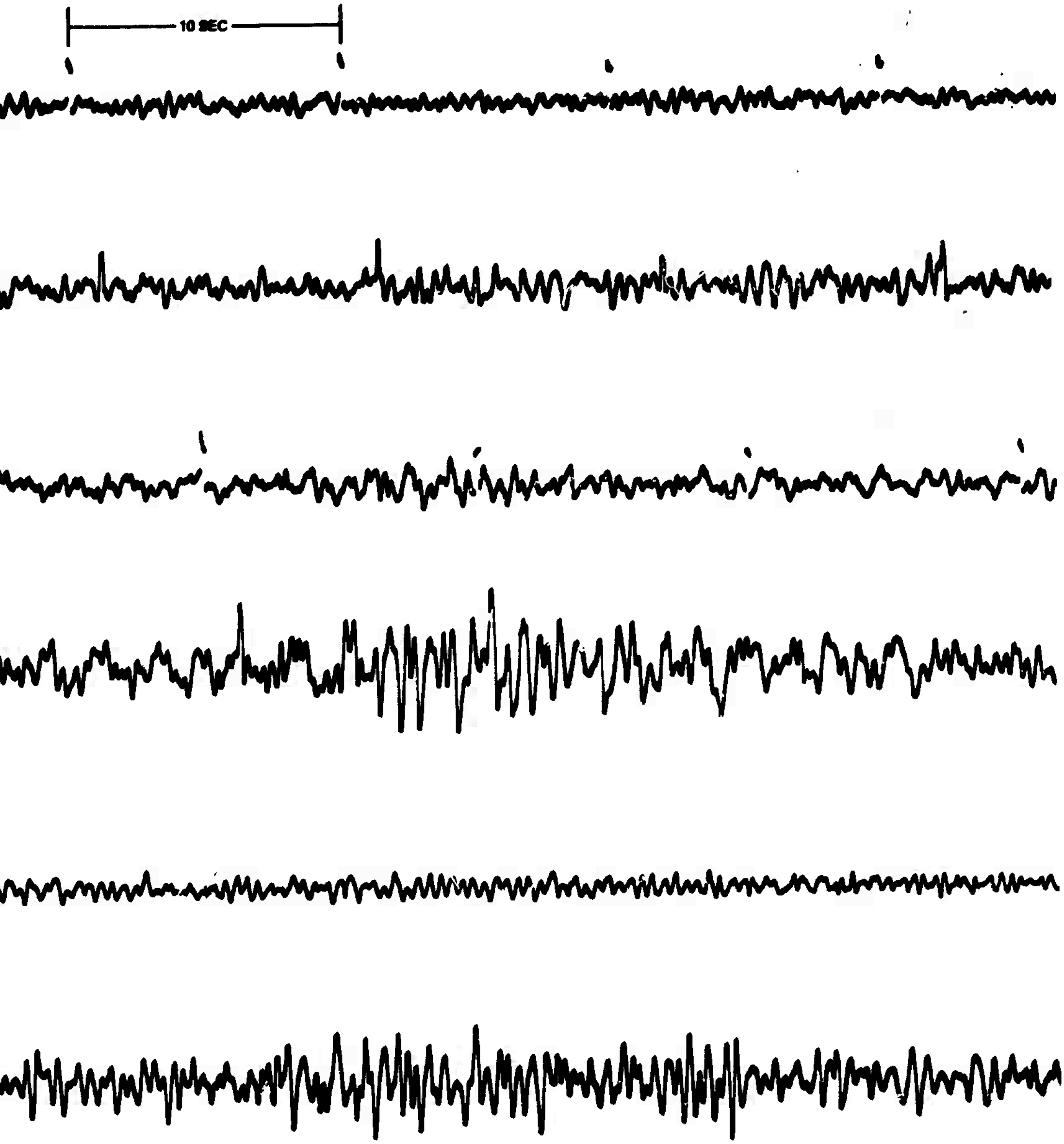
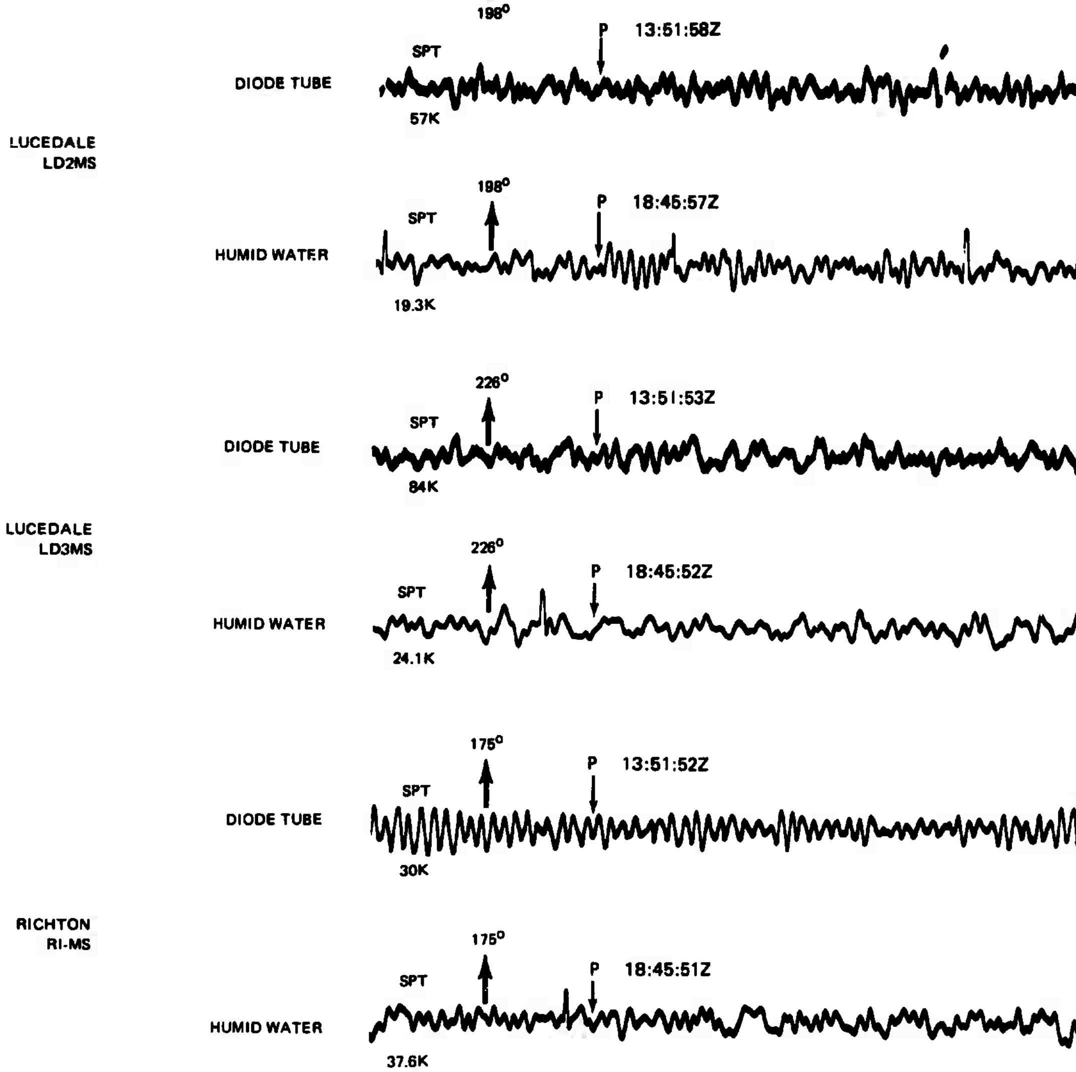



Figure 7. DIODE TUBE and HUMID WATER seismograms recorded on radial seismographs at LD2MS, LD3MS, and RI-MS. Seismograms are aligned with respect to the calculated arrival times of P.



B


LUCEDALE
LD2MS
DIODE TUBE
SPT
198°
P
13:51:58Z
57K
HUMID WATER
SPT
198°
P
18:45:57Z
19.3K
LUCEDALE
LD3MS
DIODE TUBE
SPT
226°
P
13:51:53Z
84K
HUMID WATER
SPT
226°
P
18:45:52Z
24.1K
RICHTON
RI-MS
DIODE TUBE
SPT
175°
P
13:51:52Z
30K
HUMID WATER
SPT
175°
P
18:45:51Z
37.6K

A

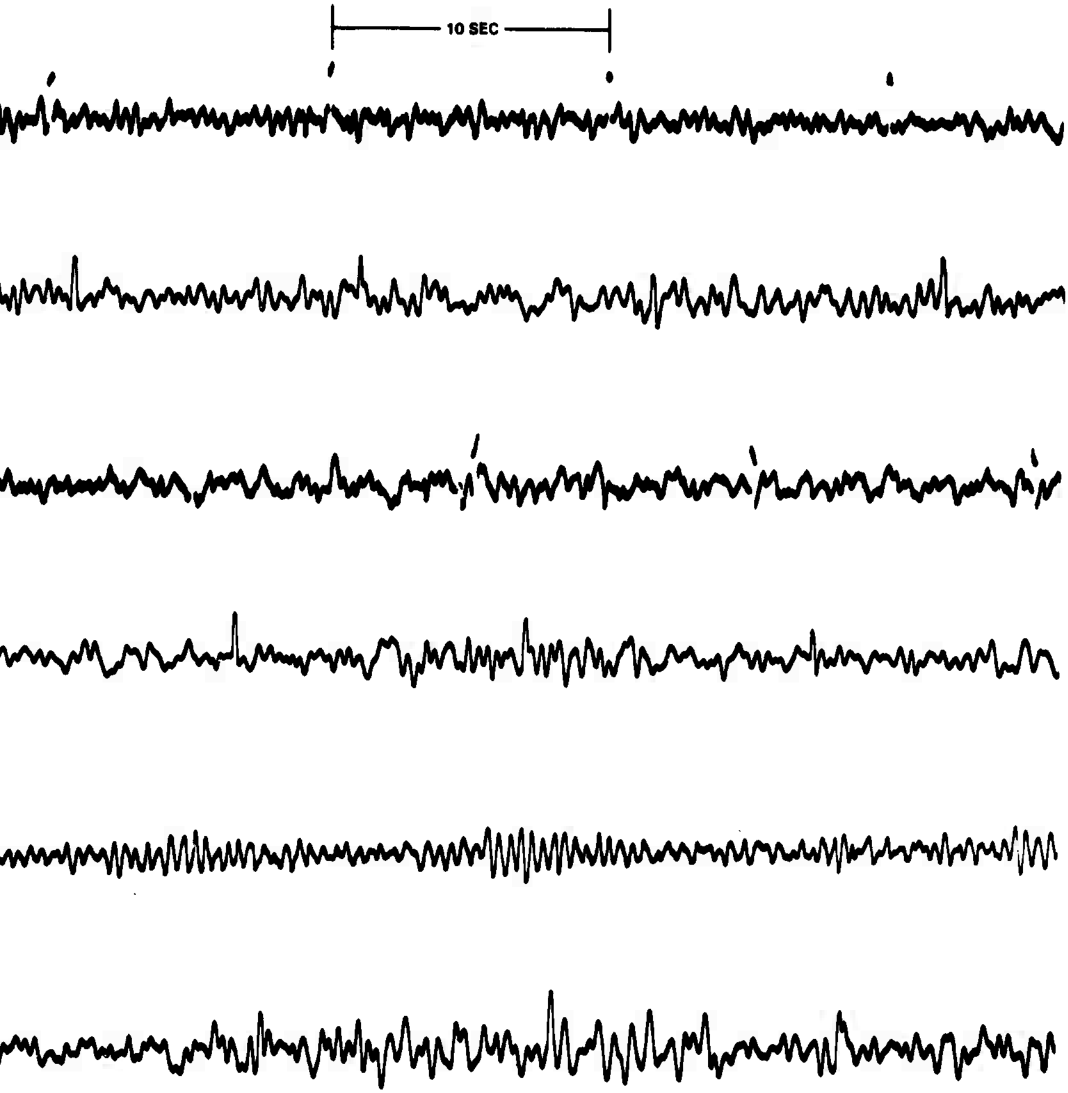
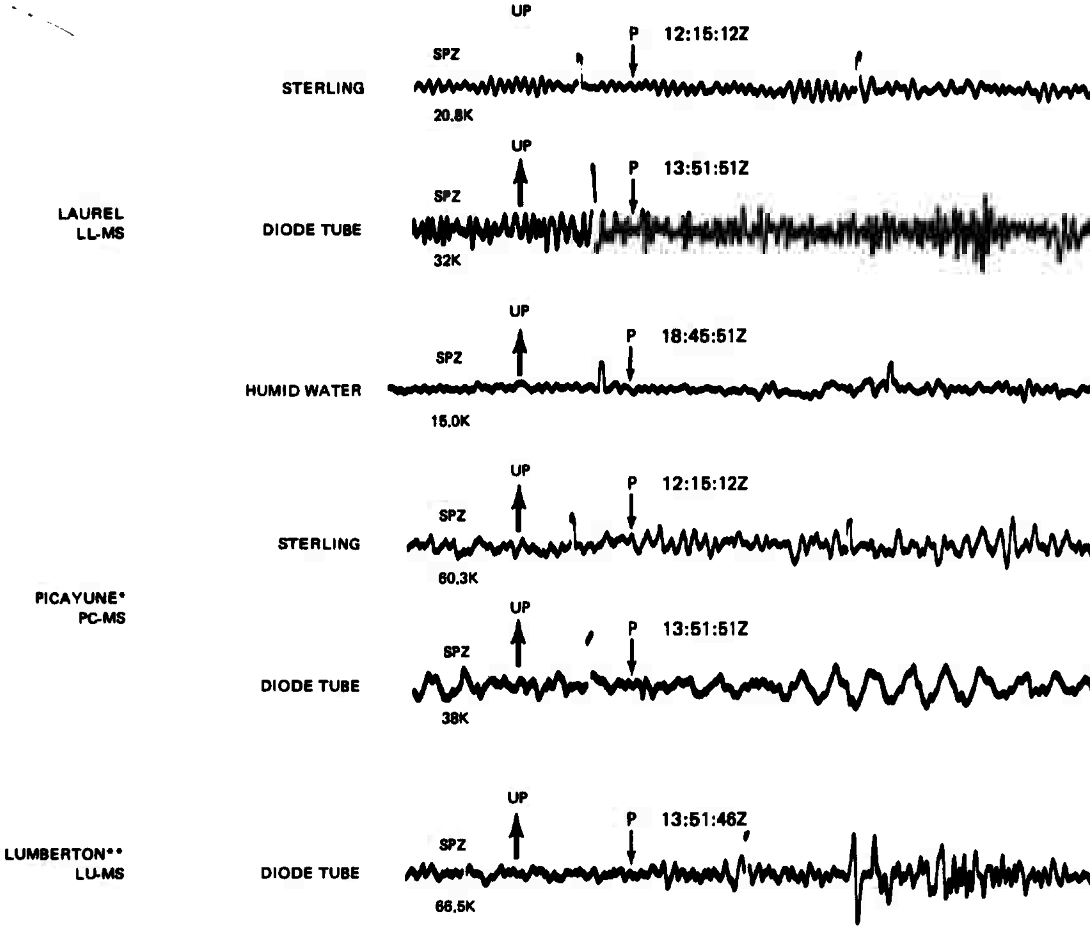



Figure 8. DIODE TUBE and HUMID WATER seismograms recorded on transverse seismographs at LD2MS, LD3MS, and RI-MS. Seismograms are aligned with respect to the calculated arrival times of P.





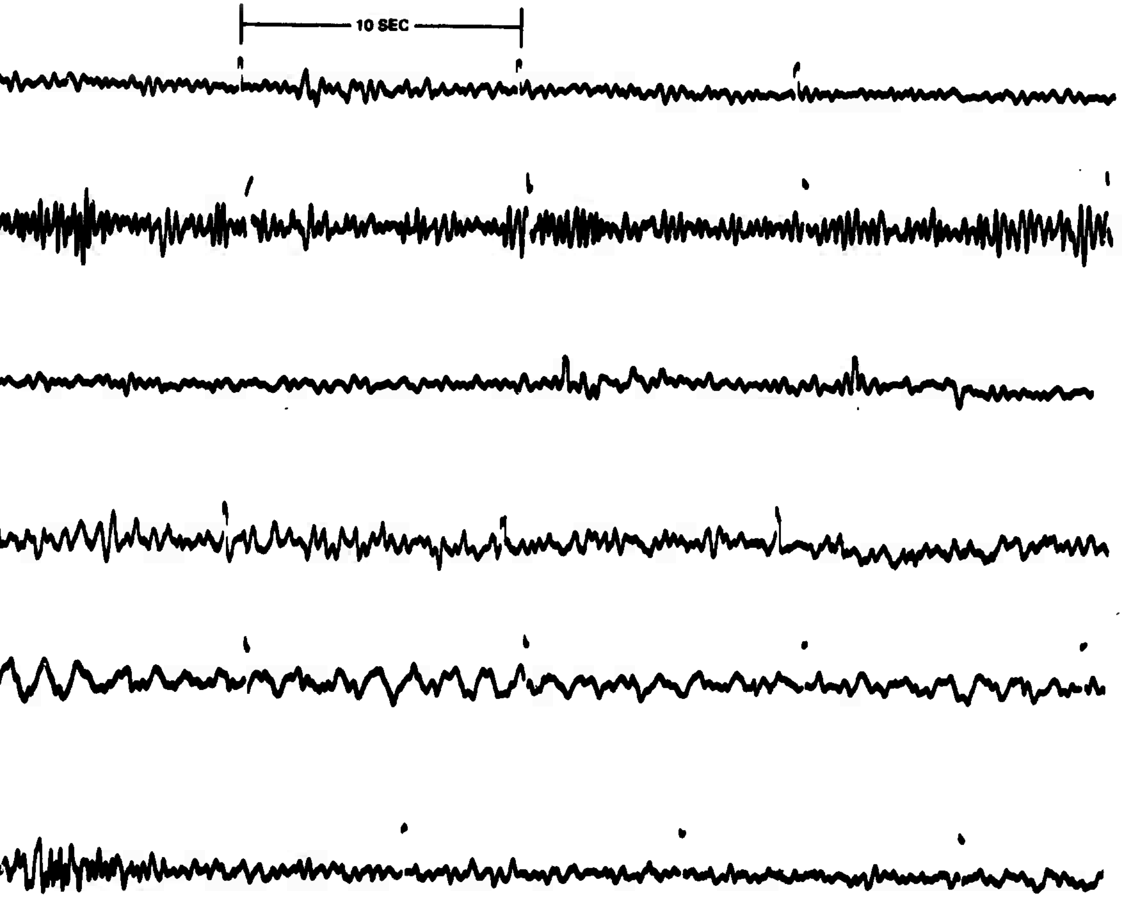
B




* MAINTENANCE WAS BEING PERFORMED AT PC-MS DURING THE HUMID WATER EVENT — NO DATA RECORDED.

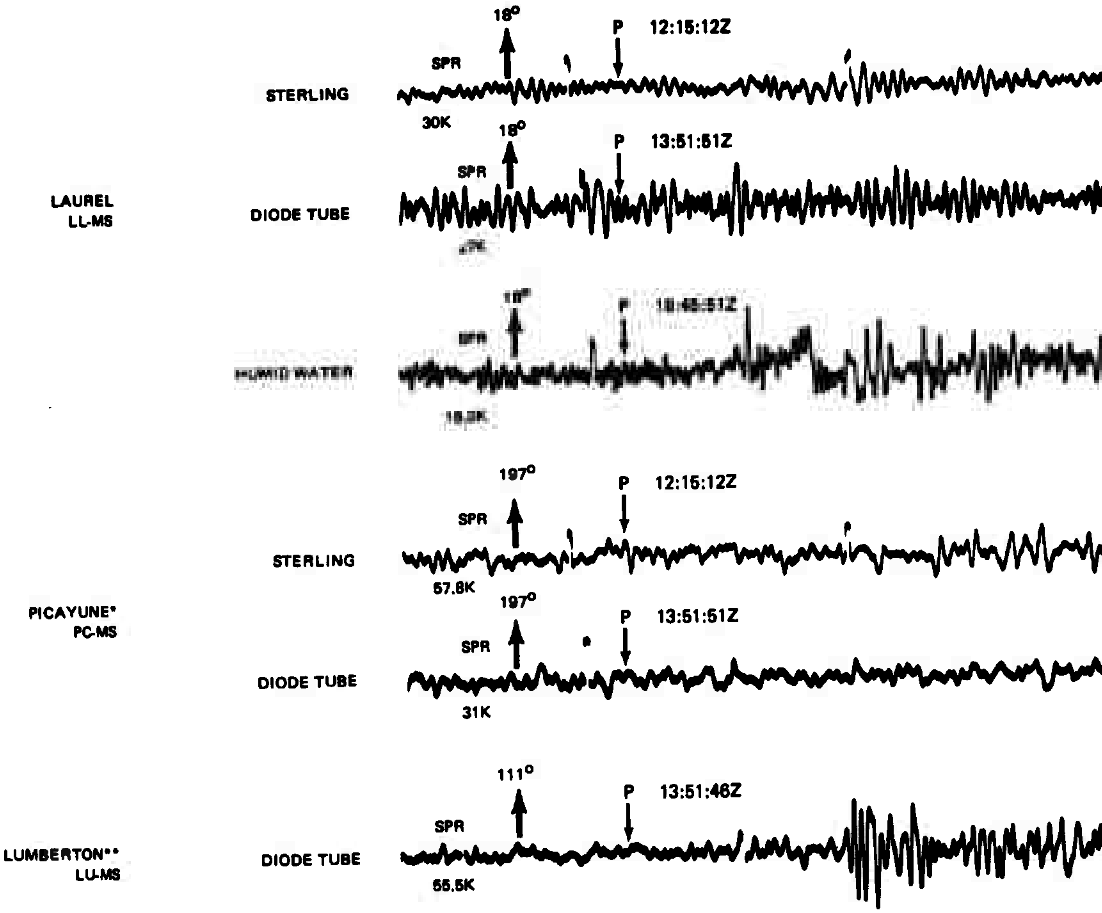
** LU-MS WAS NOT ACTIVATED AT THE TIME OF THE STERLING EVENT AND MAINTENANCE WAS BEING PERFORMED DURING THE HUMID WATER EVENT — NO DATA RECORDED.

A




B

Figure 9. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on vertical seismographs at LL-MS, PC-MS, and LU-MS. Seismograms are aligned with respect to the calculated arrival times of P.




* MAINTENANCE WAS BEING PERFORMED AT PC-MS DURING THE HUMID WATER EVENT – NO DATA RECORDED.

** LU-MS WAS NOT ACTIVATED AT THE TIME OF THE STERLING EVENT AND MAINTENANCE WAS BEING PERFORMED DURING THE HUMID WATER EVENT – NO DATA RECORDED.

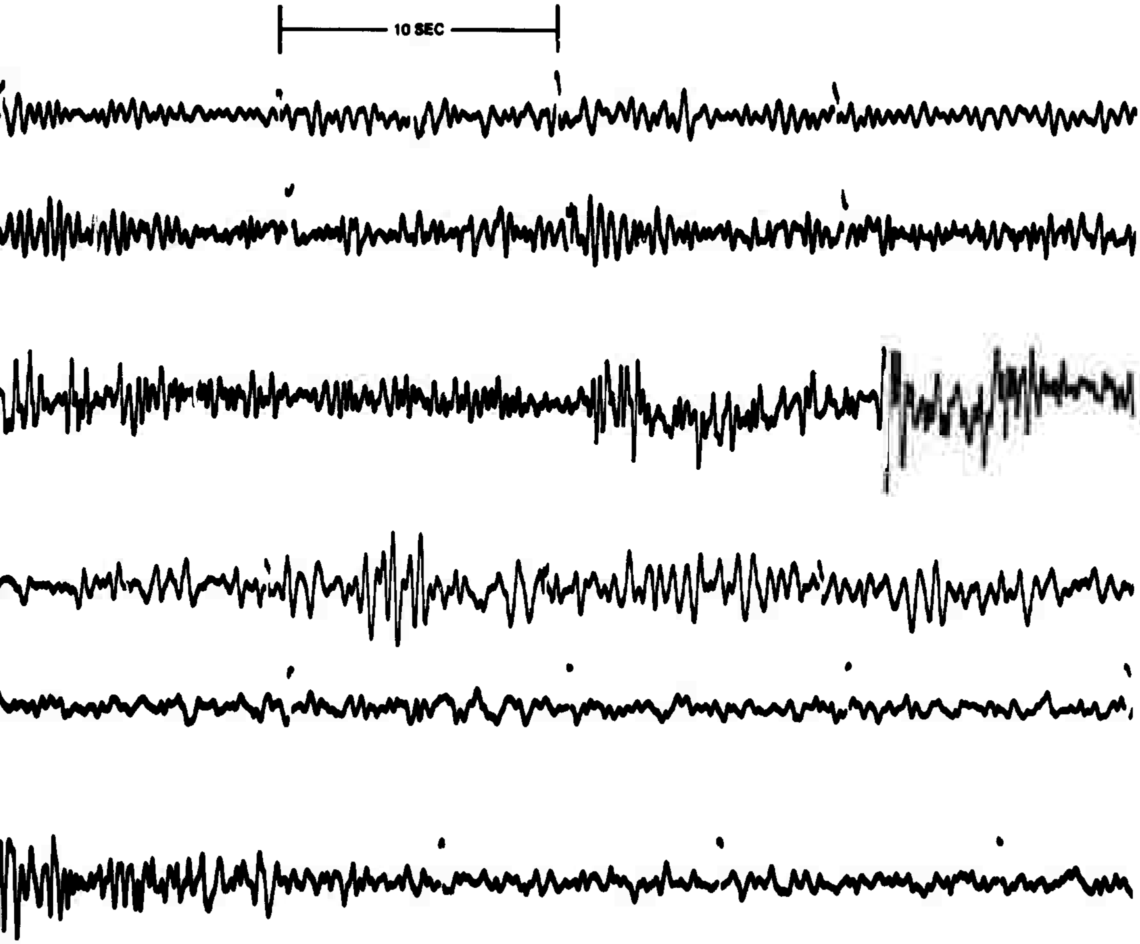
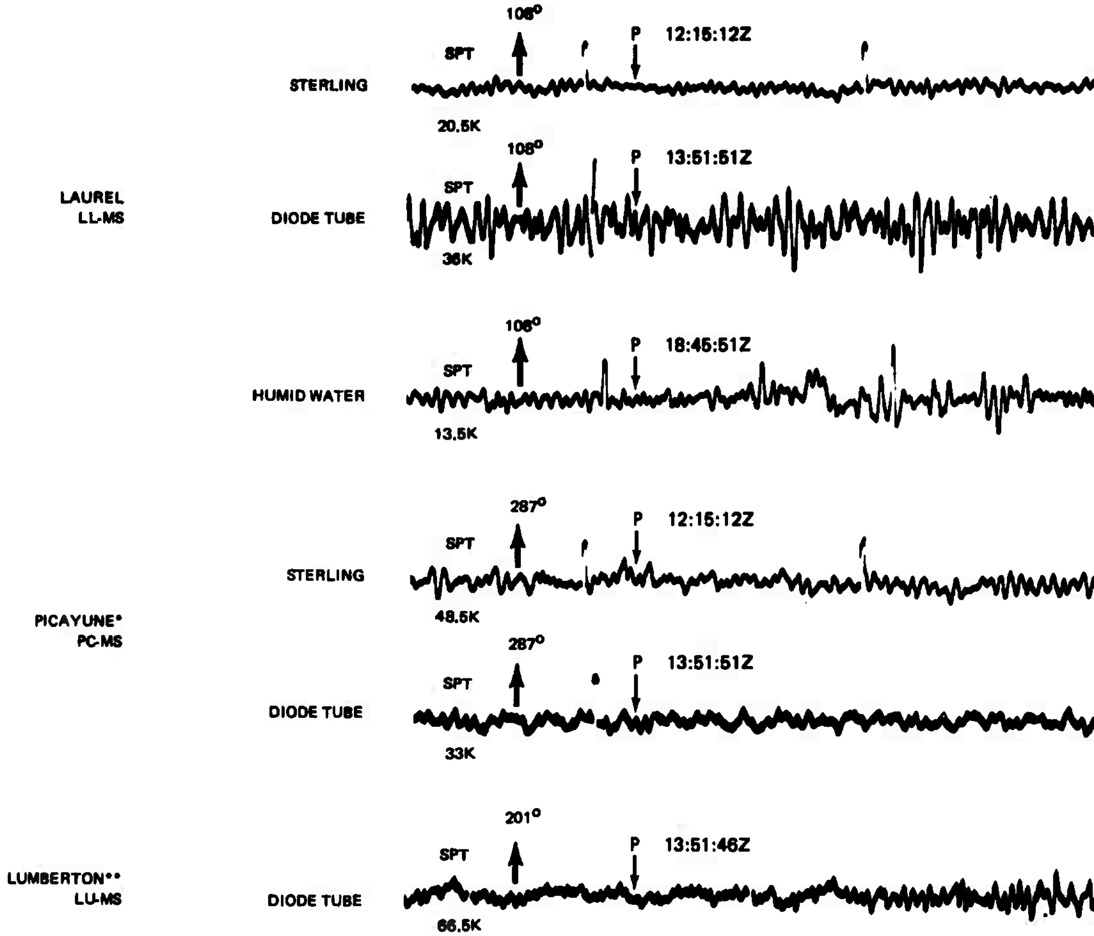



Figure 10. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on radial seismographs at LL-MS, PC-MS, and LU-MS. Seismograms are aligned with respect to the calculated arrival times of P.

B




* MAINTENANCE WAS BEING PERFORMED AT PC-MS DURING THE HUMID WATER EVENT – NO DATA RECORDED.

** LU-MS WAS NOT ACTIVATED AT THE TIME OF THE STERLING EVENT AND MAINTENANCE WAS BEING PERFORMED DURING THE HUMID WATER EVENT – NO DATA RECORDED.

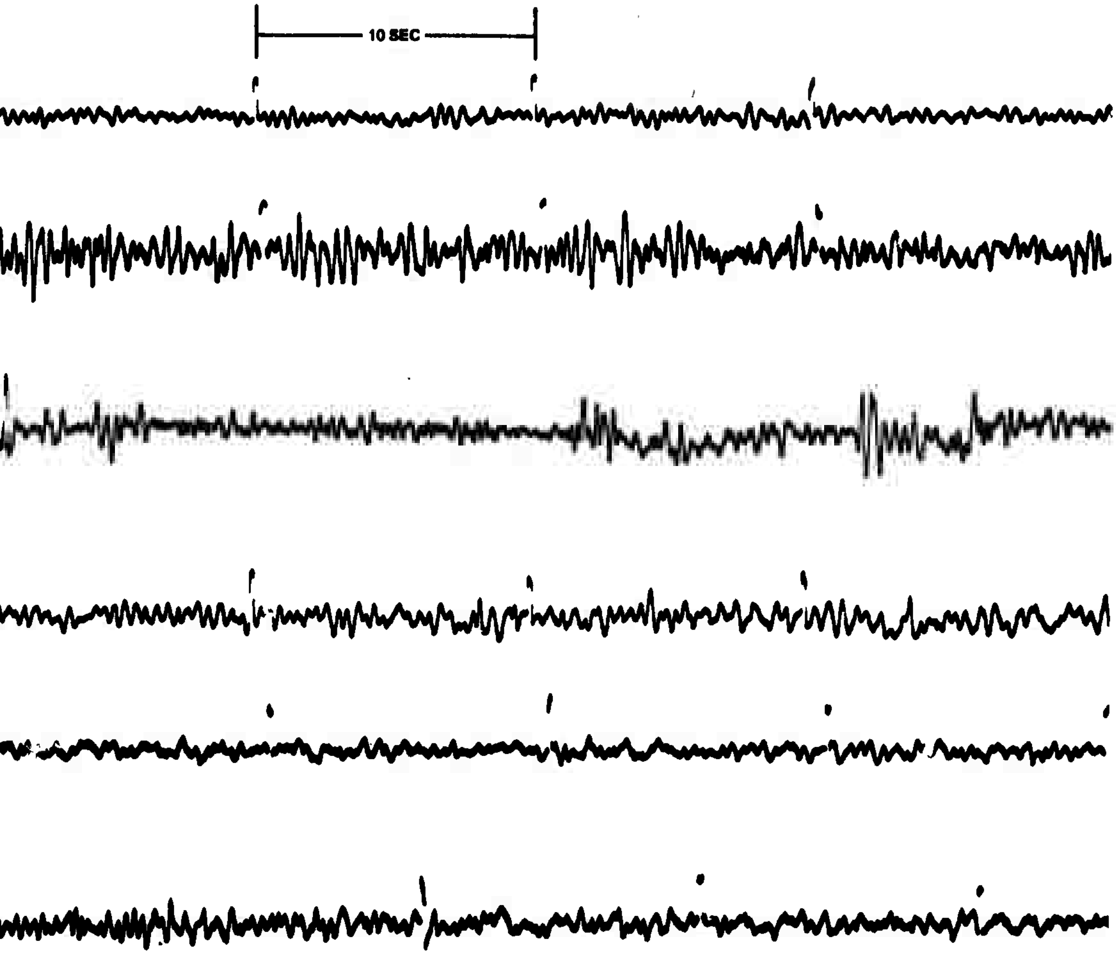



Figure 11. STERLING, DIODE TUBE, and HUMID WATER seismograms recorded on transverse seismographs at LL-MS, PC-MS, and LU-MS. Seismograms are aligned with respect to the calculated arrival times of P.

STERLING and HUMID WATER seismograms, which are identical in character, an approximate origin time of 18:45:38.4Z was determined.

Table 1 presents an analysis of the signals recorded on the radial trace at RI-MS, LD-MS, MB-MS, and LD3MS for HUMID WATER. Table 2 presents an analysis of the signals recorded at LU-MS, LD-MS, and LD3MS for DIODE TUBE and an analysis of the signal recorded on the radial trace at LD-MS for STERLING. Amplitude measurements were taken from the largest wavelet in the surface wave train. The largest signal recorded at LD-MS in the surface group from the HUMID WATER event was 1.7 times greater than the event signal recorded from the STERLING event, and 4.4 times greater than the largest signal recorded from the DIODE TUBE event.

## 4.3 SPECTRA

The short-period data from LD-MS were digitized at a rate of 20 samples per second. Power spectra of microseismic noise samples were computed from data recorded immediately preceding the STERLING, DIODE TUBE, and HUMID WATER explosion. The resulting spectra from the vertical, radial, and transverse seismographs are illustrated in figures 12, 13, and 14. Power spectra of a 25-second signal sample, including the segment during which the surface group peaked on the radial trace, were computed. The spectra of the surface wave portion of the recordings were also computed; the spectral ratio (STERLING spectrum/HUMID WATER spectrum) is shown in figure 15.

All the analysis was done using data from LD-MS, the site with the largest signal-to-noise ratio. It must be noted that the site is anomalous in its high signal-to-noise ratios as compared with other sites at approximately the same distance.

Examination of the spectra clearly indicates the low amplitude levels recorded from DIODE TUBE. Only on the radial trace was the power level of the signal appreciably above the background noise level. The largest amplitude in the surface wave train of the radial of DIODE TUBE is 4.4 times smaller than HUMID WATER and 2.6 times smaller than STERLING. From the spectra shown in figure 13, it can be computed that in the frequency range of appreciable power (1.0 - 3.0 Hz) the power ratio shows that DIODE TUBE is smaller by a factor of approximately 100 than HUMID WATER, and approximately a factor of 20 smaller than STERLING. On the short-period vertical trace, the spectra indicate that the signal power does not exceed the confidence level (±4 dB) of the noise, i.e., no measureable signal power was detected over the whole signal range, although the surface wave train can be detected visually. The difference between radial and vertical cannot be explained satisfactorily at this time.

Table 1. HUMID WATER analysis

| Station | Δ in km | Phase | Arrival time | Travel time in seconds | Instrument & gain | | Amp in mm | Period | A (mμ)[1] p-p |
|---|---|---|---|---|---|---|---|---|---|
| Lumberton LU-MS | 33.4 | Inoperative | | | | | | | |
| Laurel LL-MS | 67.4 | No signal recorded* | | | | | | | |
| Picayune PC-MS | 68.1 | Inoperative | | | | | | | |
| Richton RI-MS | 68.8 | Sur | 18:46:10.0[2] | 31.6 | SPR | 41.1K | 15 | 0.5 | 365 |
| Lucedale LD-MS | 68.9 | Sur | 18:46:08.6 | 30.2 | SPR | 68.6K | 65 | 0.4 | 948 |
| McComb MB-MS | 71.8 | Sur | 18:46:10.4 | 32.0 | SPR | 78.0K | 22 | 0.3 | 282 |
| Lucedale LD3MS | 72.9 | Sur | 18:46:14.8 | 36.4 | SPR | 31.1K | 20 | 0.4 | 643 |
| Lucedale LD2MS | 103.4 | No signal recorded | | | | | | | |

Long-period data analysis - no signal recorded

$$A = \frac{\text{Amp (in mm)} \times 10^3}{\text{Gain (K)}}$$

[1]Amplitudes are given for the largest wavelet and are not corrected for system response.

[2]Questionable

*Operator working on system

Table 2. DIODE TUBE analysis

| Station | Δ in km | Phase | Arrival time | Travel time in seconds | Instrument & gain | | Amp in mm | Period | A (mμ)[1] p-p |
|---|---|---|---|---|---|---|---|---|---|
| Lumberton LU-MS | 33.4 | eP[2] | 13:51:47.1 | 07.6 | SPZ | 66K | 4.0 | 0.3 | 60.6 |
| | | Sur | 13:51:53.6 | 14.1 | SPR | 55.5K | 17.0 | 0.3 | 306.3 |
| Laurel LL-MS | 67.4 | No signal | | | | | | | |
| Picayune PC-MS | 68.1 | No signal | | | | | | | |
| Richton RI-MS | 68.8 | No signal | | | | | | | |
| Lucedale LD-MS | 68.9 | Sur | 13:52:08 | 28.5 | SPR | 71.4K | 15.5 | 0.5 | 217.0 |
| | | | | | SPT | 90.9K | 16.5 | 0.5 | 181.5 |
| McComb MB-MS | 71.8 | No signal | | | | | | | |
| Lucedale LD3MS | 72.9 | Sur | 13:52:09[2] | 29.5 | SPR | 61.2K | 8.0 | 0.6 | 130.7 |
| Lucedale LD2MS | 103.4 | No signal | | | | | | | |

$$A = \frac{\text{Amp (in mm)} \times 10^3}{\text{Gain (K)}}$$

For the STERLING experiment:

| Station | Δ in km | Phase | Arrival time | Travel time in seconds | Instrument & gain | | Amp in mm | Period | A (mμ)[1] p-p |
|---|---|---|---|---|---|---|---|---|---|
| Lucedale LD-MS | 68.9 | Sur | 12:15:30.2 | 30.2 | SPR | 146K | 83.5 | 0.5 | 570.0 |

[1]Amplitudes are given for the largest wavelet and are not corrected for system response.

[2]Questionable

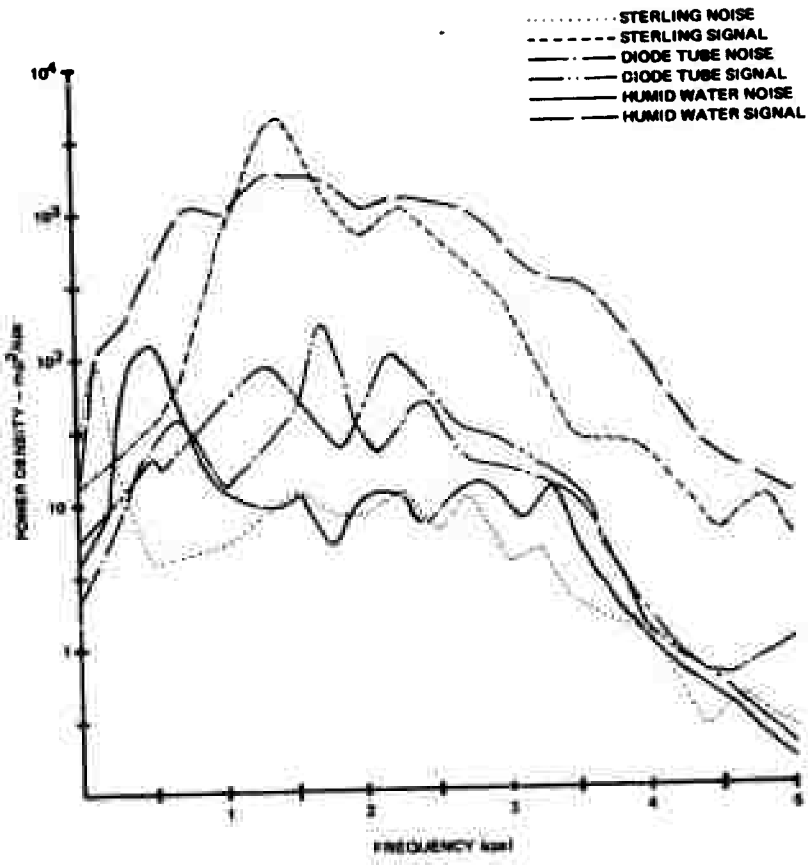



Figure 12. Comparative spectra of background noise recorded on vertical seismographs at LD-MS prior to STERLING (3 December 1966), DIODE TUBE (2 February 1969), and HUMID WATER (19 April 1970), and spectra of respective signals.

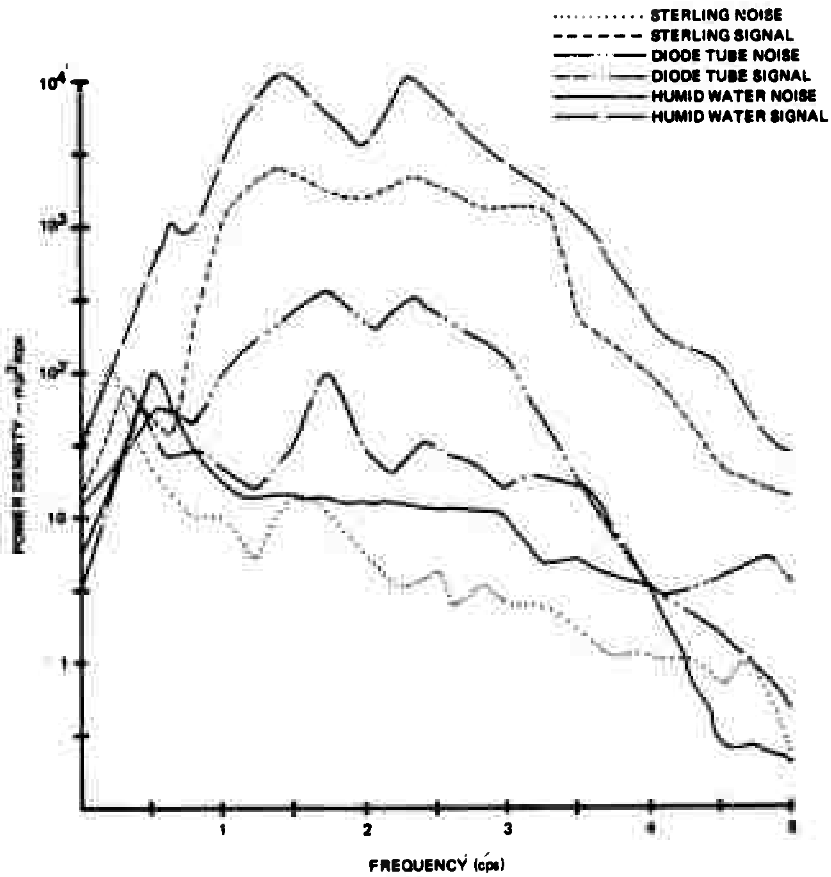



Figure 13. Comparative spectra of background noise recorded on radial seismographs at LD-MS prior to STERLING (3 December 1966), DIODE TUBE (2 February 1969) and HUMID WATER (19 April 1970), and spectra of respective signals.

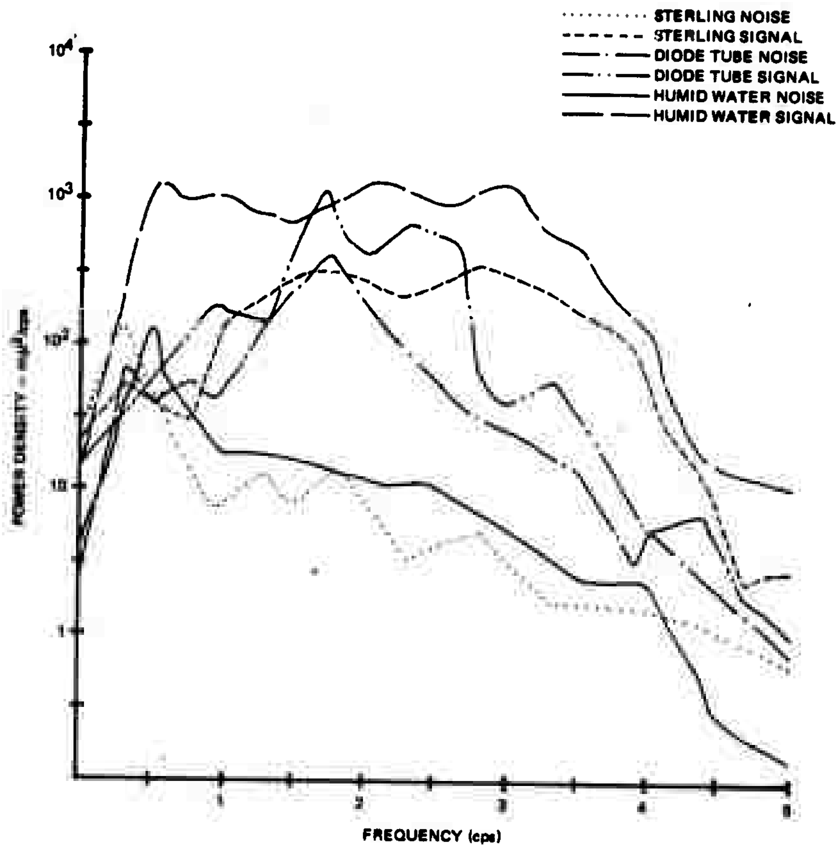



Figure 14. Comparative spectra of background noise recorded on transverse seismographs at LD-MS prior to STERLING (3 December 1966), DIODE TUBE (2 February 1969), and HUMID WATER (19 April 1970), and spectra of respective signals.

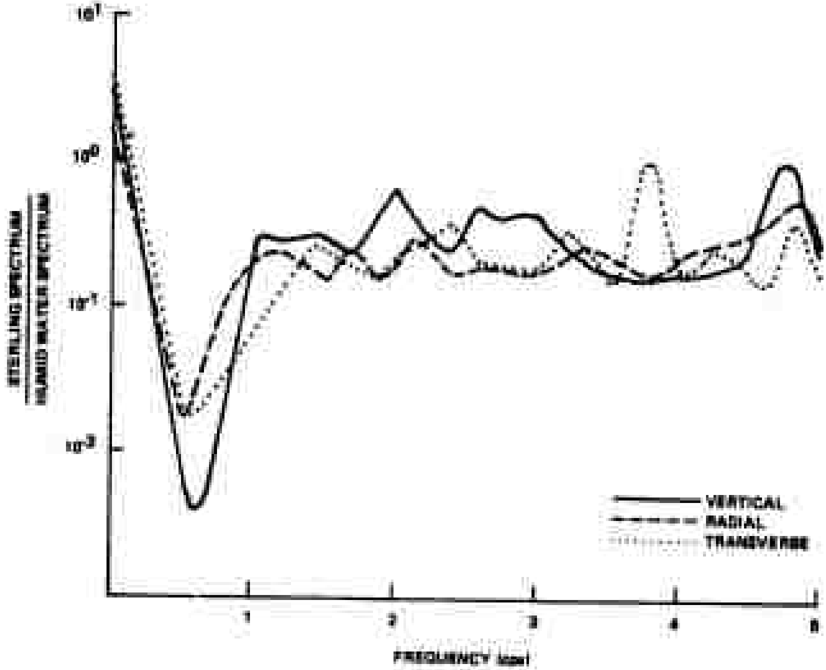



Figure 15. Spectral ratio of surface wave train from STERLING and HUMID WATER

Because of the low signal level of DIODE TUBE, the remainder of the analysis concentrated on the STERLING and HUMID WATER signals.

On computing the spectra of the surface-wave trains of these two events, an interesting behavior was noted. Referring to figure 15 where the spectral ratio is shown, the following two facts are apparent:

a. For all three components the spectral ratio is approximately the same in the frequency range between 1.0 and 5.0 Hz, with average values between 0.3 and 0.5.

b. For periods between 1.0 and 0.5 Hz, the HUMID WATER surface-wave train has a large amount of energy as compared to STERLING.

A comparison of the surface wave spectra (not illustrated) and the preceding noise shows that STERLING has little energy in this frequency range, while HUMID WATER has appreciable energy in this frequency range (see figure 12). Because travel path and receiver location are identical, the difference must be caused by the source mechanism. For some reason, not understood by the author, a decoupled nuclear explosion produced less energy in the frequency range of 1.0 to 0.5 Hz than a gas explosion. Further studies of this phenomenon would involve a detailed study of the source mechanism.

Because there is no appreciable difference in the frequency band of the signal and the noise, it was decided not to use a band-pass filter to attempt to improve the signal-to-noise ratio. In an attempt to improve the signal-to-noise ratio of the first arrival, the P wave, a prediction error filter was designed (Peacock and Treitel, 1969)[1]. The prediction filter uses the statistics of the preceding noise to predict the noise at the time of signal arrival and subtracts it from the record, leaving the signal unaffected. It must be noted that only the first arrival is improved; later in the record, the filter is operating on signal plus noise and the results are unreliable. The results for STERLING and HUMID WATER are shown in figures 16 and 17. No appreciable improvement of the first arrival was obtained, probably because of the almost flat spectrum of the noise.

It is recommended that any further analysis concentrate on the surface wave train where an adequate signal-to-noise ratio is present. Relating the behavior of surface waves back to source differences will necessitate a more lengthy study than was possible at this time.

---

[1]Peacock, K. L., and Treitel, S., 1969: Predictive deconvolution; Theory and practice: Geophysics, vol. 34, p. 155-169

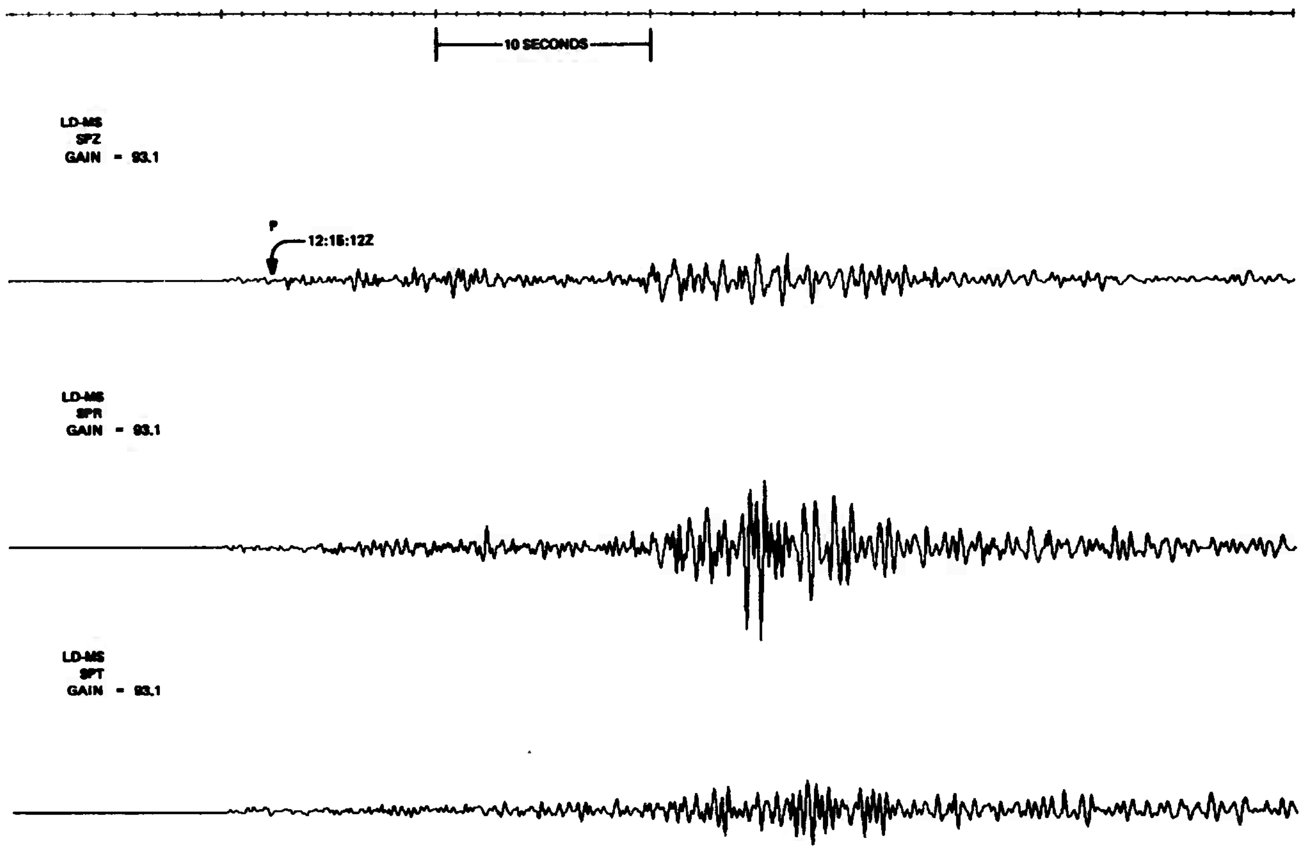
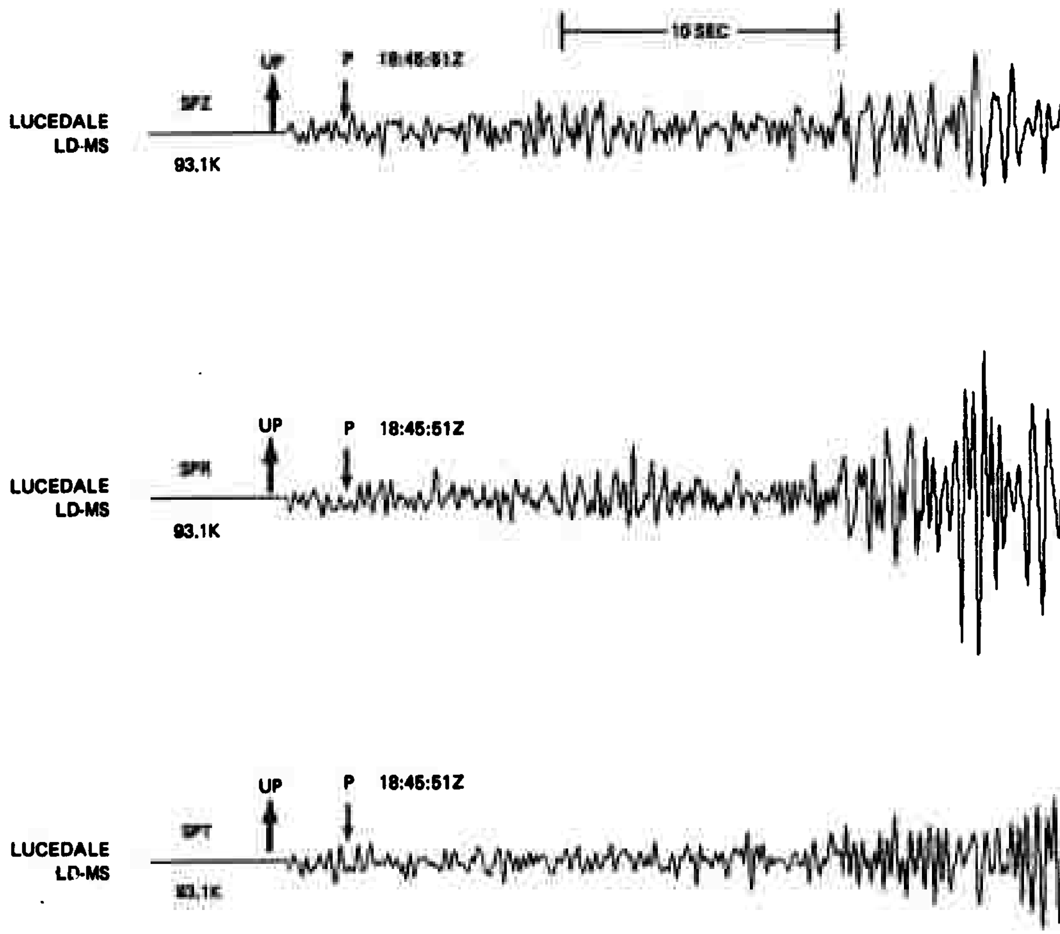
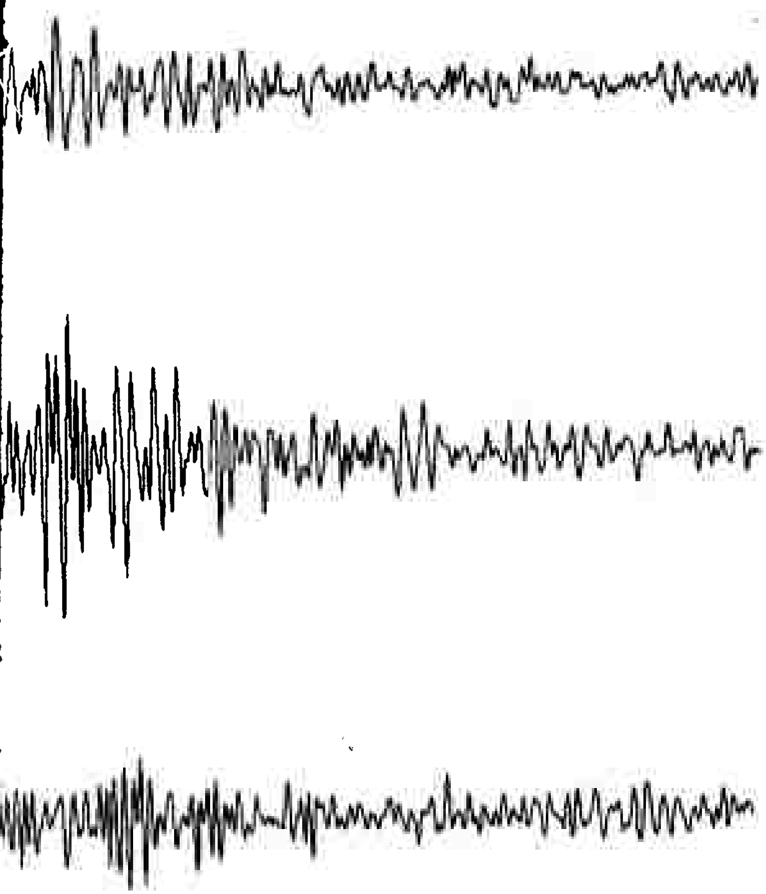



Figure 16. Result of using a prediction error filter on the recordings from event STERLING


10 SEC
UP
P
LUCEDALE
LD-MS
93.1K
UP
P 18:45:51Z
SPR
LUCEDALE
LD-MS
93.1K
UP
P 18:45:51Z
SPT
LUCEDALE
LD-MS
93.1K

A



B

Figure 17. Result of using a prediction error filter on the recordings from event HUMID WATER

## 5. SUMMARY

The background noise level prior to STERLING was slightly lower than the background noise prior to HUMID WATER. The signal energy from the HUMID WATER shot was greater than the signal energy from the STERLING shot. Amplitude measurements taken from the largest wavelet in the surface wave train indicate that the HUMID WATER signal was 1.7 times greater than the STERLING signal. Attempts to improve the signal-to-noise ratio of the P wave from the STERLING and HUMID WATER events by using a prediction error filter proved unsuccessful.

## 6. ACKNOWLEDGMENTS

The author is grateful to Dr. Eduard Douze, consultant for this report, for his technical advice, editing support, and assistance in preparing the spectral analysis section.

APPENDIX 1 to TECHNICAL REPORT NO. 70-16

## GEOLOGY OF SITES

## GEOLOGY OF SITES

### A. Laurel, Mississippi (LL-MS)

Vaults were emplaced in a reddish to ocher colored, compact, very sandy, silty clay. The sand is fine grained, fair sorted, and subangular. The deposits are continental in origin of the Catahoula Sandstone Formation of Tertiary age. The up-section Citronelle Formation is exposed in a gravel pit about 3 miles east of the site. Gentle, regional dips of less than 1 degree to the southwest are typically present in the area. Compared to other site locales in the Gulf Coast Plain, the deep subsurface structure is complex. The site is in the Mississippi Salt Basin. Salt domes are as near as about 5 kilometers (3 miles). Block fault zones are about 5 kilometers to the north and 14 kilometers to the southeast (3 miles N and 9 miles SE). The thickness of the Tertiary sediments, unconformably overlying the higher velocity Cretaceous rocks, is about 1692 meters (est. 5550 feet). Petroleum prospects in the area have tested the Hosston Formation, the basal formational unit of the Lower Cretaceous System, at about 4115 meters (est. 13,500 feet) below sea level. The buried Ouachita Tectonic Belt, that zone of folded and faulted Paleozoic rocks, is present in the subsurface at greater depths. On page 3451 of a 1966 publication[1] by Warren, Healy, and Jackson of the USGS is a north-south crustal section through the DRIBBLE shot point. Extrapolation of the crustal data indicates the following general layering in the subsurface at the Laurel site (the section is, of course, more complex):

| Strata | Approximate depths below sea level | Velocity |
|---|---|---|
| Tertiary | 0-2 kilometers | 3.0 km/sec (assumed) |
| Mesozoic and older? | 2-10 kilometers | 4.9 to 5.1 km/sec |
| Remaining upper crust | 10-15 kilometers | 5.8 km/sec |
| Lower crust | 15-32 kilometers | 6.9 km/sec |
| Top of upper mantle | at about 32 kilometers | 8.4 km/sec (below the Moho discontinuity) |

Data in the referenced report suggest deepening of the top of the Upper Crustal 6 km/sec horizon in the Collins, Mississippi area. The Mississippi Salt Basin is the prime subsurface feature contributing to the velocity layering in the shallow crust of the location.

---

[1]Warren, D. H., Healy, J. H., and Jackson, W. H., 1966, Crustal Seismic Measurements in Southern Mississippi: JGR, v. 71, no. 14

B. Lucedale, Mississippi (LD-MS)

Seismometers were emplaced in gray, weathering to reddish brown, very clayey, soft, unconsolidated, compact, fair sorted, fine to medium grained, subangular sand. This continental deposit contains scattered, rounded granules of quartz. The sediment is a portion of the Citronelle Formation of Tertiary age. Regional dip is gentle to the southwest at less than 1 degree. The soft, unconsolidated Tertiary sediments have a thickness of about 1716 meters (est. 5630 feet) in this area unconformably overlying rocks of Cretaceous age. The strong subsurface feature of the locale is the east-west trending Wiggins Uplift, a complex structural high. Basin facies sediments thin across this uplift. The site is just north of the Cretaceous crest of this structure, and those beds dip northerly towards the East Mississippi Syncline of the Mississippi Salt Basin. A successful petroleum prospect, the Phillips No. A-1 Josephine, completed in 1965, penetrated the Louann Salt Formation of Jurassic-Permian age at about 6096 meters (est. 20,000 feet) below sea level. This deep gas well is approximately 8 kilometers (5 miles) west-southwest of the site.

C. Lucedale, Mississippi (LD2MS)

The seismometers were emplaced upon a reddish tan, incompetent, sandy, silty clay. This clay is a residual soil from the deeply weathered underlying Citronelle Formation, which is of Tertiary age. The Citronelle is a continental deposit of massive, red, cross-bedded, fine-grained, uncemented, clayey sand. Regional dip of this formation is gentle to the southwest at less than 1 degree. The Tertiary sediments have a total thickness of approximately 1676 meters (5,500 feet) in this area unconformably overlying rocks of Cretaceous age. The strong subsurface feature in this region is the Wiggins Uplift, a complex structural high. Basin facies sediments thin across this uplift. The site is south of the Cretaceous crest of this structure, and beds dip to the south. A successful petroleum prospect, The Phillips No. A-1 Josephine, completed in 1965, penetrated the Louann Salt Formation of the Jurassic-Permian age at about 6096 meters (est. 20,000 feet) below sea level. This deep gas well is approximately 40 kilometers (25 miles) west of the site. No known salt domes exist in this general area. The basement complex is at a depth between 7315 meters (24,000 feet) and 8534 meters (28,000 feet) in this area.

The site is situated on a hill just west of the Cedar Creek, which drains to the south. Relief, as measured from the hill on which the site is located, to the Cedar Creek is about 34 meters (110 feet). Most of the region is heavily forested with areas that have been cleared for farming or have been cut and only second growth trees are now standing. This second growth is fairly thin, reaching a maximum height of 8 meters (25 feet).

D. Lucedale, Mississippi (LD3MS)

The seismometers were emplaced upon a reddish tan, incompetent, sandy, silty clay. This clay is a residual soil from the deeply weathered underlying Citronelle Formation, which is of Tertiary age. The Citronelle is a continental deposit of massive, red, cross-bedded, fine-grained, uncemented, clay sand. Regional dip of this formation is gentle to the southwest at less than 1 degree. The Tertiary sediments have a total thickness of approximately

1829 meters (6,000 feet) in this area unconformably overlying rocks of Cretaceous age. The strong subsurface feature in this region is the Wiggins Uplift, a complex structural high. Basin facies sediments thin across this uplift. The site is south of the Cretaceous crest of this structure, and beds dip to the south. A successful petroleum prospect, the Phillips No. A-1 Josephine, completed in 1965, penetrated the Louann Salt Formation of the Jurassic-Permian age at about 6096 meters (est. 20,000 feet) below sea level. This deep gas well is approximately 32 kilometers (20 miles) north of the site. No known salt domes exist in this general area. The basement complex is at a depth between 7315 meters (24,000 feet) and 8534 meters (28,000 feet) in this area.

The site is situated on the low divide between the Bridge Branch and the Spike Buck Creek. These creeks drain east into the Boggy Branch Creek. Relief, as measured from the hills in the site area to the Bridge Branch, is about 9 meters (30 feet). This site area is heavily forested with pine trees, with small clearings. The site is located in one of these small clearings, surrounded by pines of about 23 meters (75 feet) maximum height.

E. Lumberton, Mississippi (LU-MS)

Seismometers were set on a yellowish to buff, loose, clayey, fine-grained sand. This sand is a residual soil of the deeply weathered underlying Citronelle Formation of Tertiary age. The Citronelle is a continental deposit of massive, red, cross-bedded, fine-grained, uncemented, clayey sand. Regional dip of this formation is gentle to the southwest at less than 1 degree. The Tertiary sediments have a total thickness of approximately 1676 meters (est. 5,500 feet) in this area unconformably overlying rocks of Cretaceous age. The strong subsurface feature of the locale is the east-west trending Wiggins Uplift, a complex structural high. The site is located on the northwest flank of this uplift. Basin facies sediments thin across this uplift, and dip to the north towards the East Mississippi Syncline of the Mississippi Salt Basin. A successful petroleum prospect, the Phillips No. A-1 Josephine, completed in 1965, penetrated the Louann Salt Formation of the Jurassic-Permian age at about 6095 meters (est. 20,000 feet) below sea level. This deep gas well is approximately 27 kilometers (18 miles) southeast of the site. An east-west trending fault, down-thrown to the north, is about 8 kilometers (5 miles) south of the site. Located north-northeast of the site approximately 10 kilometers (6 miles) is an intrusive salt dome. The basement complex is at a depth between 7315 meters (24,000 feet) and 8534 meters (28,000 feet).

The site is situated on relatively high ground just south of the Black Creek, which drains the area to the east. Relief, measured from the hills in the site area to the Black Creek, is about 49 meters (160 feet). The area is in a forest region covered primarily with moderate to dense pine trees with areas that have been cleared. The site is located within one of these cleared areas.

F. McComb, Mississippi (MB-MS)

Vaults were emplaced in reddish, soft, clayey, packed, fair sorted, coarse to very coarse grained, subangular, ferruginous stained, unconsolidated sand. Deposits are primarily red sands and sandy clays with sandy gravel lenses.

An anomalous outcrop of brown, resistant, ferruginous conglomerate and sandstone was noted about 2.5 miles southwest of the site. These sediments are continental in origin and are of the Citronelle Formation of Tertiary age. The gentle, regional dip of less than 1 degree to the southwest prevails at this site. The location is on the southern edge of the Mississippi Salt Basin, and on the north flank of the west-northwest trending South Mississippi Uplift. The top of the higher velocity Cretaceous rocks is at about 2530 meters depth (est. 8,300 feet). The Lower Tuscaloosa Formation, the basal unit of the Upper Cretaceous System, was reached at about 3231 meters (est. 10,600 feet) below sea level in a petroleum prospect about 2 kilometers (1.2 miles) southwest of the site. This hole is the Southwest Gas Prod. - R. E. Williams No. 1 McEwen, drilled in 1964. The Ruth Salt Dome is about 5.6 kilometers (3.5 miles) to the north.

G. Picayune, Mississippi (PC-MS)

Seismometers were planted in a buff, sandy, silty clay of the Quarternary Coastal Deposits. Lenses of coarse sand and gravel, poorly sorted with subangular to subround grains, are noted in the area. This material is estuarine to continental in origin. Two gravel pits, within 2.8 miles north-northwest of the site, exhibit formational exposures. The location on the Lower Gulf Coast Plain, rests upon a very thick sequence of primarily incompetent basin facies sediments. There are no strong structural features in the site area. Regional dip is gentle to the southwest, at less than 1 degree. The east-west Baton Rouge Fault Zone is about 29 kilometers (18 miles) south of the site. This zone is a system of major normal faults down-thrown to the south. Thickness of the Cenozoic sediments is about 2347 meters (est. 7,700 feet) to the top of the Cretaceous rocks. On page 3451 of a 1966 publication by Warren, Healy, and Jackson of the USGS[2], in a north-south crustal section through the DRIBBLE shot point, extrapolation of the crustal data indicates the following general layering in the subsurface at Picayune (the section is, of course, more complex):

| Strata | Approximate depths below sea level | Velocity |
|---|---|---|
| Tertiary | 0-2 kilometers | 3.0 km/sec (assumed) |
| Mesozoic & older? | 2-7 kilometers | 5.1 km/sec |
| Remaining upper crust | 7-20 kilometers | 6.0 km/sec |
| Lower crust | 20-41 kilometers | 6.9 km/sec |
| Top of upper mantle | At about 41 kilometers | 8.3 km/sec (below the Moho discontinuity) |

[2] Warren, D. H., Healy, J. H., and Jackson, W. H., 1966, Crustal Seismic Measurements in Southern Mississippi: JGR, v. 71, no. 14

Data in the report suggest a gradual, northerly dip of the top of the Upper Crustal 6.0 km/sec horizon from near Ansley, Mississippi, to the Collins, Mississippi, area. Westerly trending elements of the Wiggins Uplift probably contribute to this northerly dip of the 5.1 km/sec to 6.0 km/sec velocity discontinuity.

H. Richton, Mississippi (RI-MS)

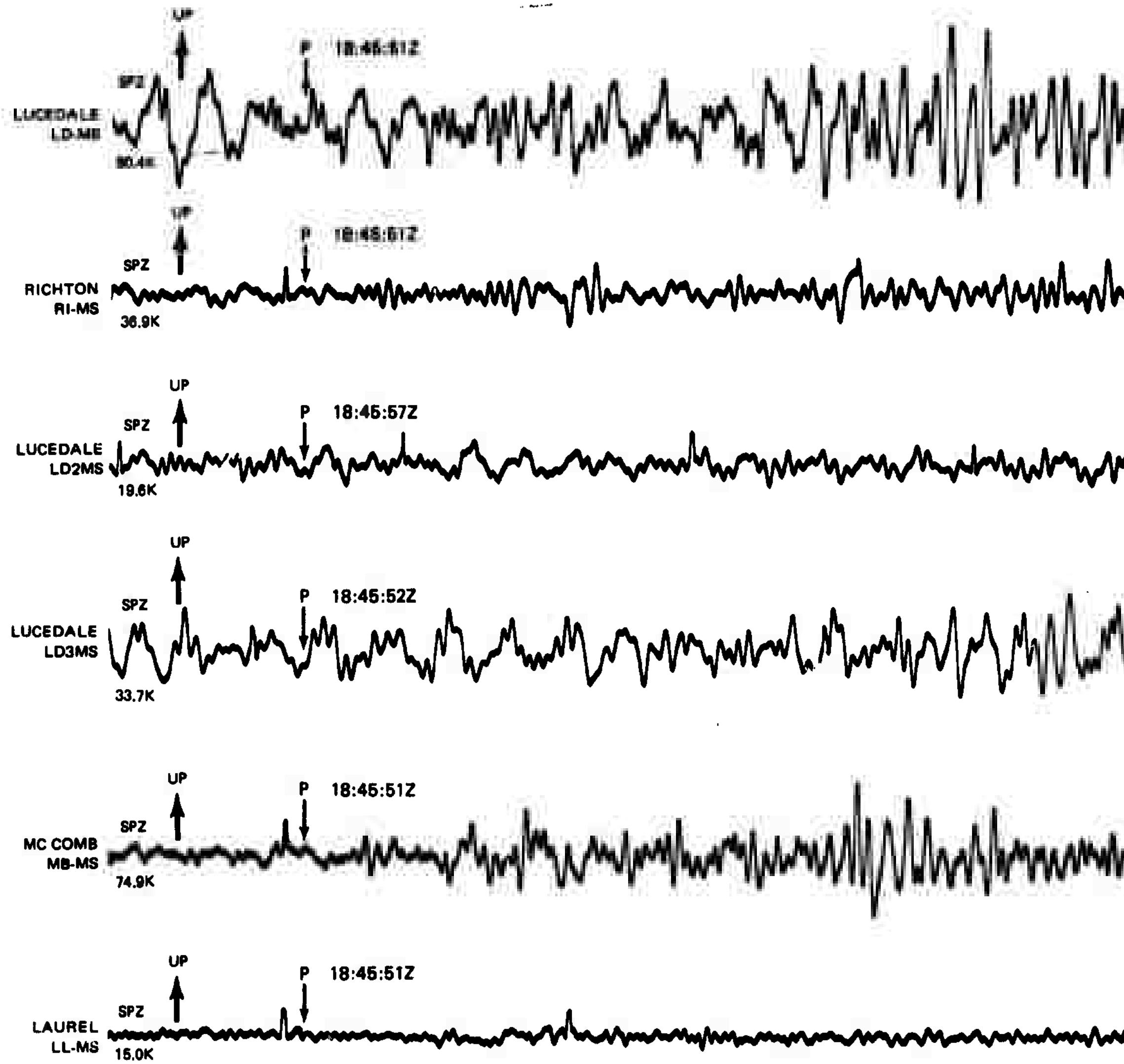
The seismometers were emplaced upon an incompetent, tan, fine-grained, clayey sand. This is a residual soil of the deeply weathered underlying Pascagoula and Hattiesburg clays, which are of Tertiary age. These clays are mainly composed of green and bluish-green clay and sandy clay with some sand and gray siltstone. Regional dip of this formation is gentle to the southwest at less than 1 degree. The Tertiary sediments have a total thickness of approximately 1676 meters (est. 5,500 feet) in this area unconformably overlying rocks of Cretaceous age. There are two strong subsurface features affecting this locality. To the south is the Wiggins Uplift trending east-west and to the northwest is the Hatchetigbee Anticline trending northwest-southwest. The entire Hatchetigbee Anticline has been highly faulted. These faults have formed numerous grabens, which trend generally northwest-southeast. The nearest faulting to the site is approximately 24 kilometers (15 miles) north. The site is located on the extreme southwestern flank of the Hatchetigbee Anticline. A successful petroleum prospect, the Cities Service 1 Robinson, completed in 1967, penetrated the Jurassic at about 6248 meters (20,500 feet) below sea level. This deep gas well is approximately 18 kilometers (11 miles) northeast of the site. There are also three (3) known intrusive salt domes in this area. Two domes are northwest of the site about 16 kilometers (10 miles) and 21 kilometers (13 miles), and the other dome occurs approximately 16 kilometers (10 miles) east-northeast of the site. The basement complex is at a depth between 7315 meters (24,000 feet) and 8534 meters (28,000 feet).

The site is situated on the relatively high ground just west of the Gaines Creek, which drains south into the Leaf River. Relief, as measured from the Gaines Creek to the hills in the site area, is about 15 meters (50 feet). This area is heavily forested with pine trees, with areas that have been cleared for farming. The site is located in one of the clearings.

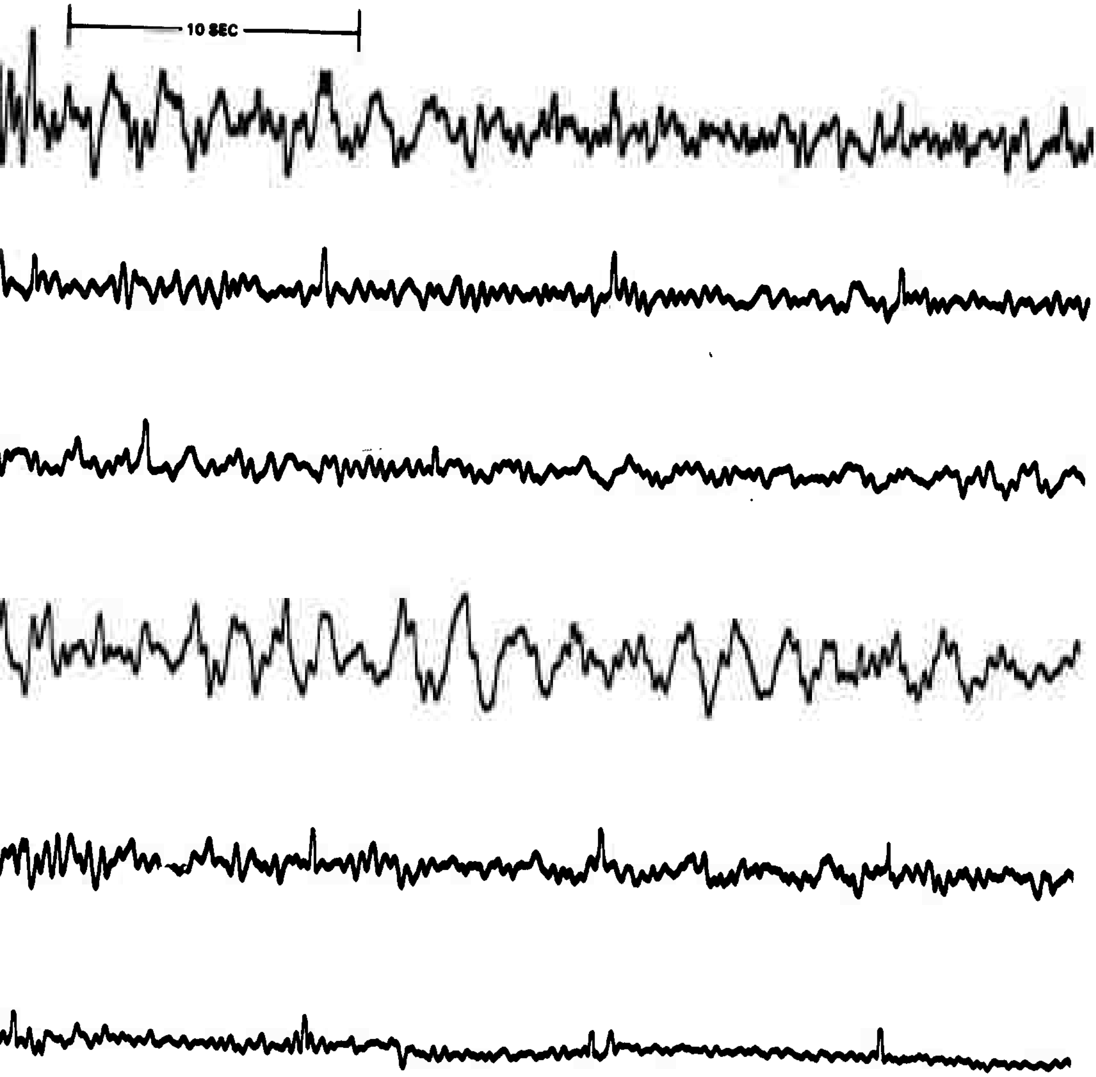
APPENDIX 2 to TECHNICAL REPORT NO. 70-16

HUMID WATER SEISMOGRAMS

## ILLUSTRATIONS

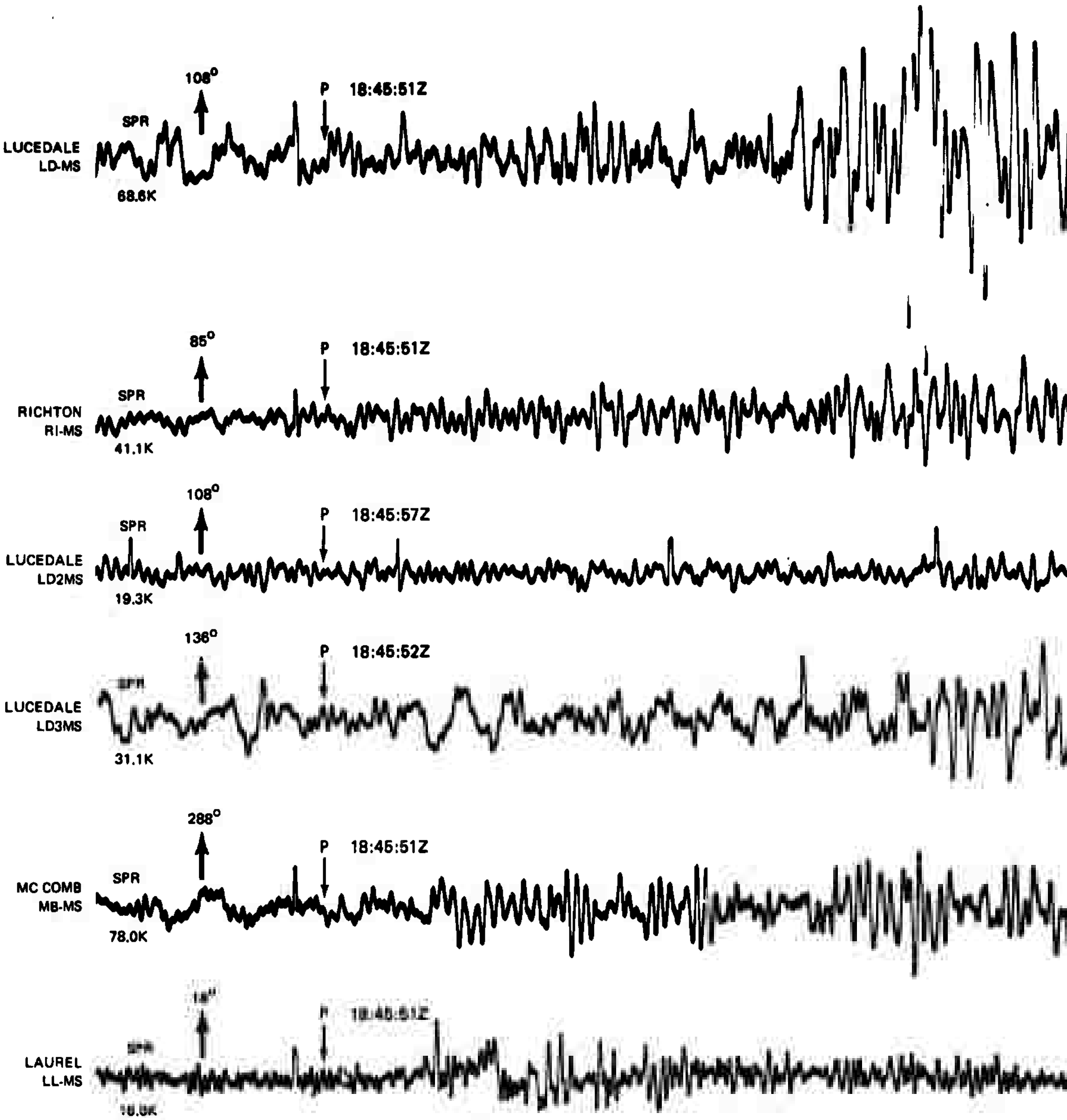

UP
P 18:45:51Z
RICHTON
RI-MS
SPZ
36.9K
UP
P 18:45:57Z
SPZ
LUCEDALE
LD2MS
19.6K
UP
P 18:45:52Z
SPZ
LUCEDALE
LD3MS
33.7K
UP
P 18:45:51Z
SPZ
MC COMB
MB-MS
74.9K
UP
P 18:45:51Z
SPZ
LAUREL
LL-MS
15.0K

A




13

Figure 1. HUMID WATER seismograms recorded on vertical seismographs at LD-MS, RI-MS, LD2MS, LD3MS, MB-MS, and LL-MS. Seismograms are aligned with respect to the calculated arrival times of P.



LUCEDALE
LD-MS
SPR
108°
P 18:45:51Z
68.6K
RICHTON
RI-MS
SPR
85°
P 18:45:51Z
41.1K
LUCEDALE
LD2MS
SPR
108°
P 18:45:57Z
19.3K
LUCEDALE
LD3MS
136°
P 18:45:52Z
31.1K
MC COMB
MB-MS
SPR
288°
P 18:45:51Z
78.0K
LAUREL
LL-MS


A

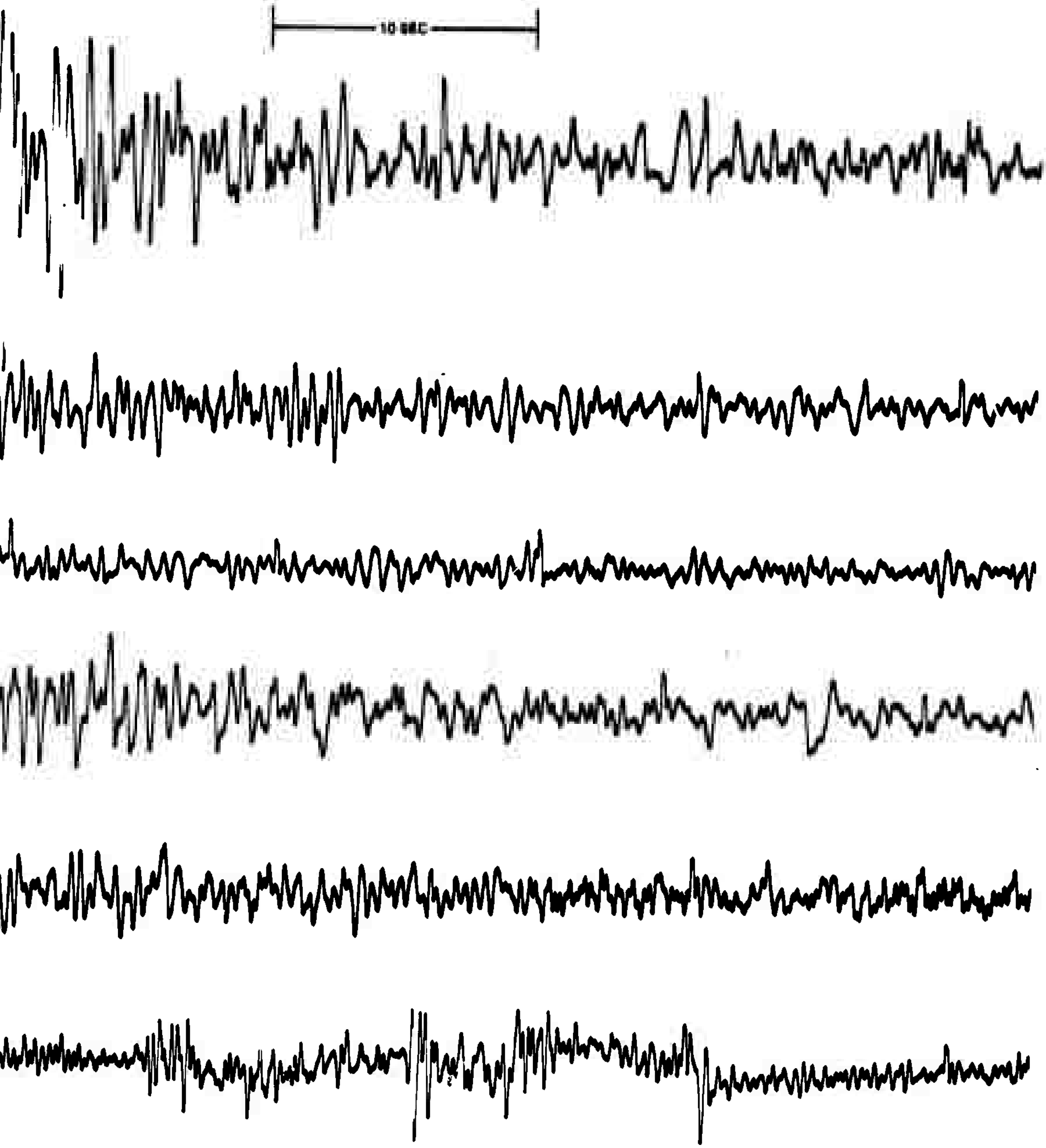
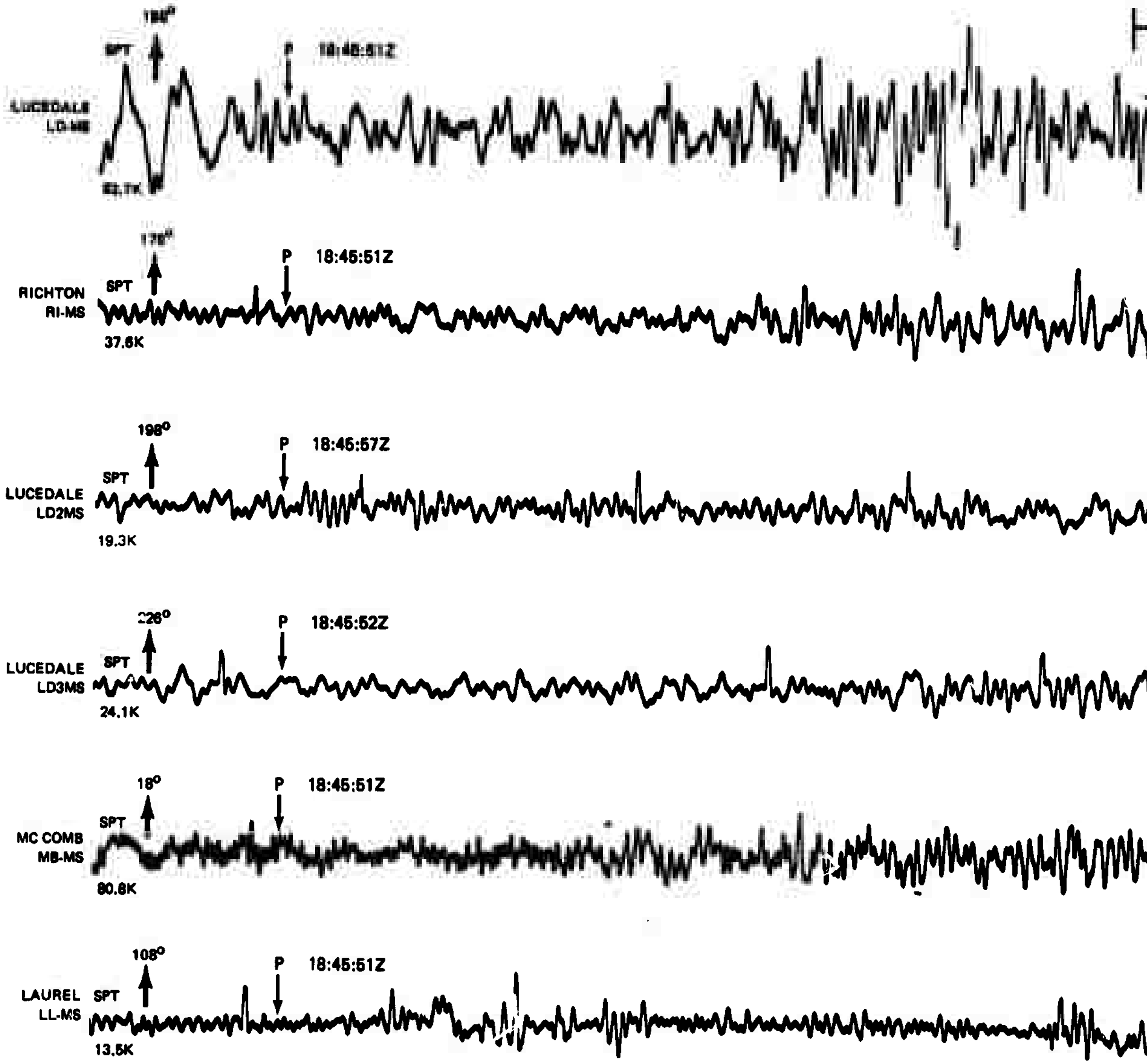



Figure 2. HUMID WATER seismograms recorded on radial seismographs at LD-MS, RI-MS, LD2MS, LD3MS, MB-MS, and LL-MS. Seismograms are aligned with respect to the calculated arrival times of P.



B


RICHTON
RI-MS
SPT
170°
P
18:45:51Z
37.6K
LUCEDALE
LD2MS
SPT
198°
P
18:45:57Z
19.3K
LUCEDALE
LD3MS
SPT
226°
P
18:45:52Z
24.1K
MC COMB
MB-MS
SPT
18°
P
18:45:51Z
80.8K
LAUREL
LL-MS
SPT
108°
P
18:45:51Z
13.5K

A

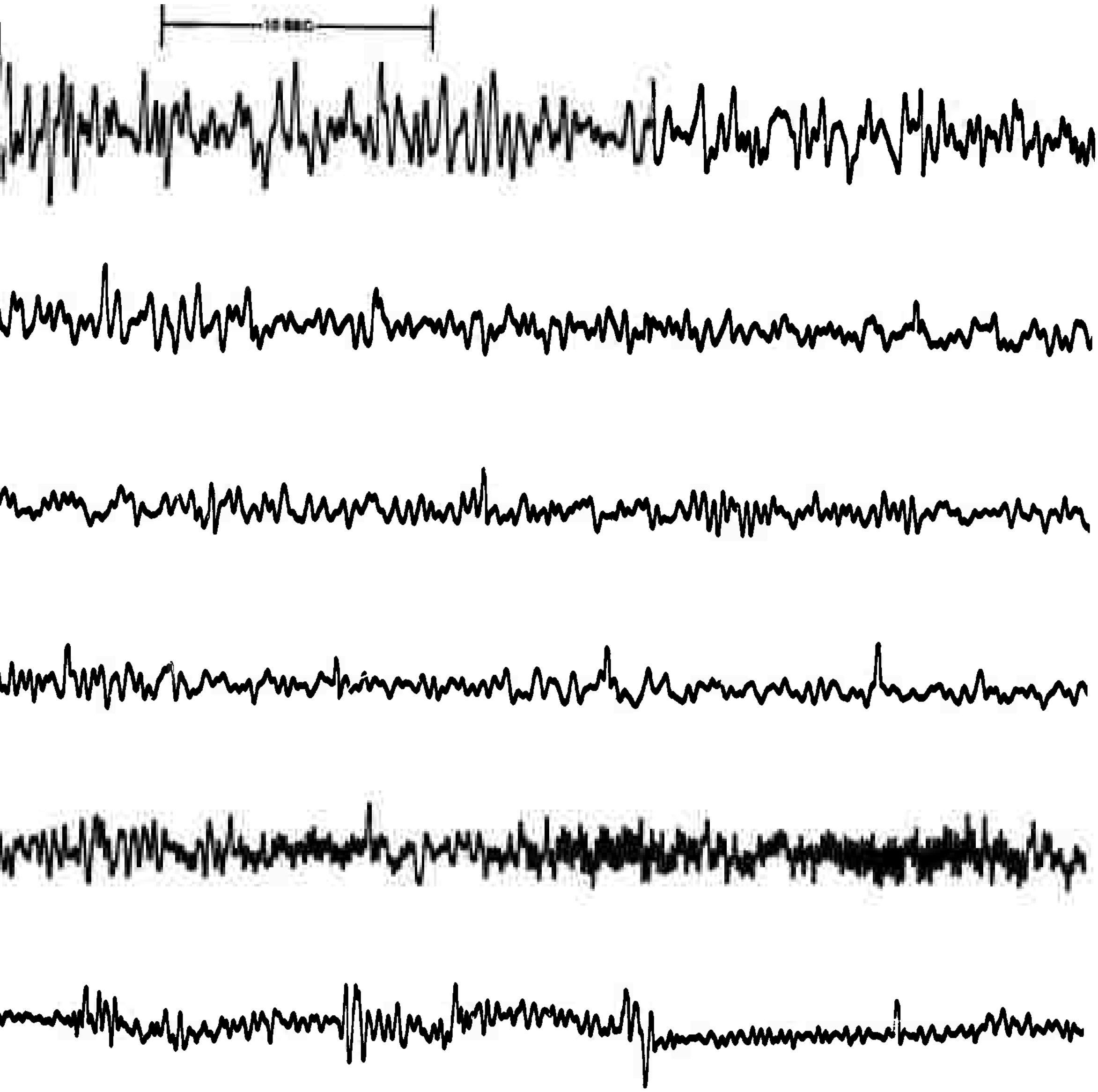
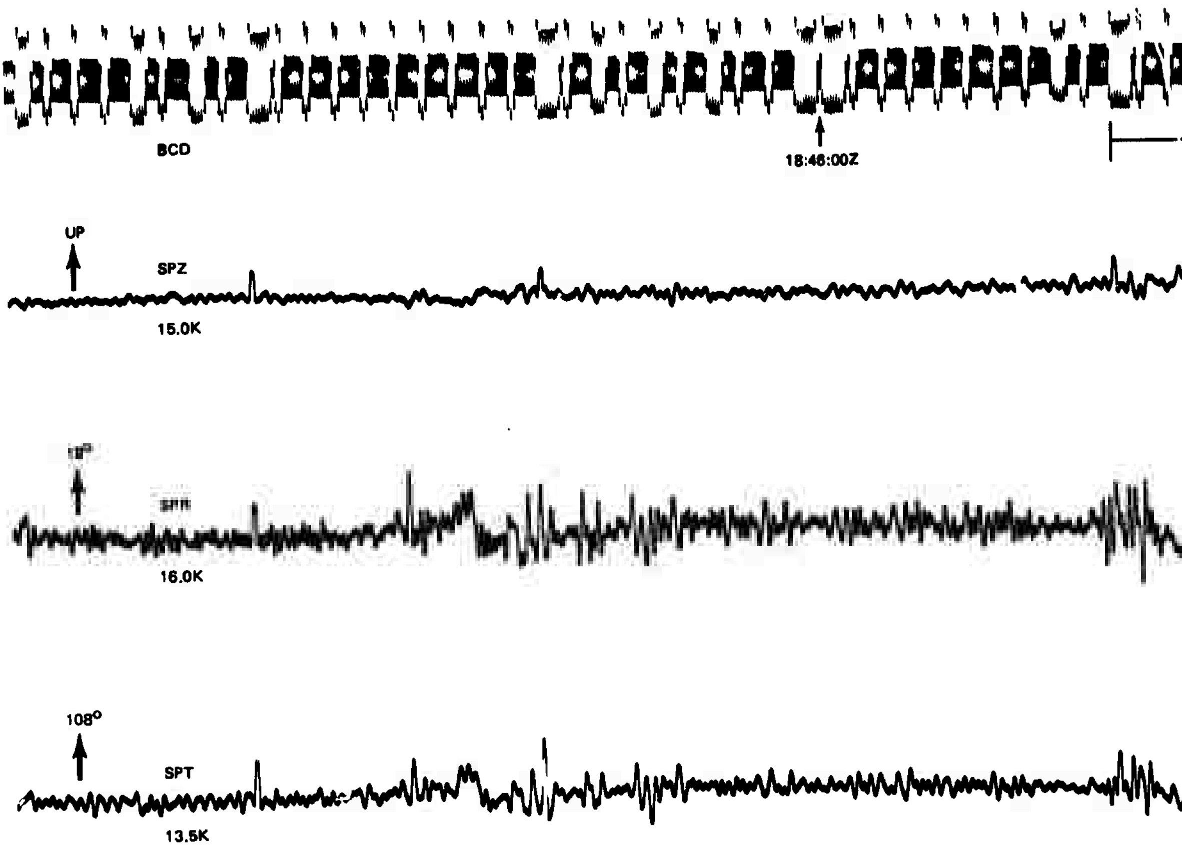
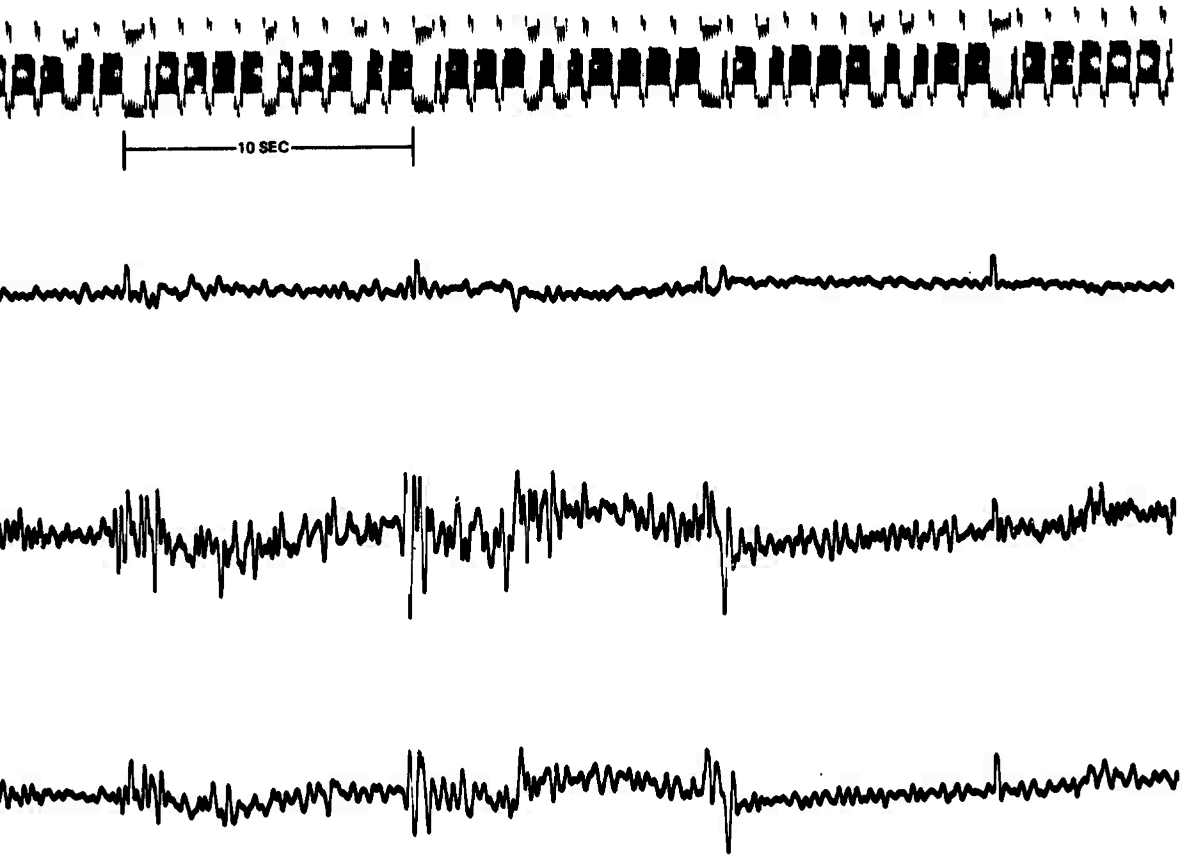


Figure 3. HUMID WATER seismograms recorded on transverse seismographs at LD-MS, RI-MS, LD2MS, LD3MS, MB-MS, and LL-MS. Seismograms are aligned with respect to the calculated arrival times of P.

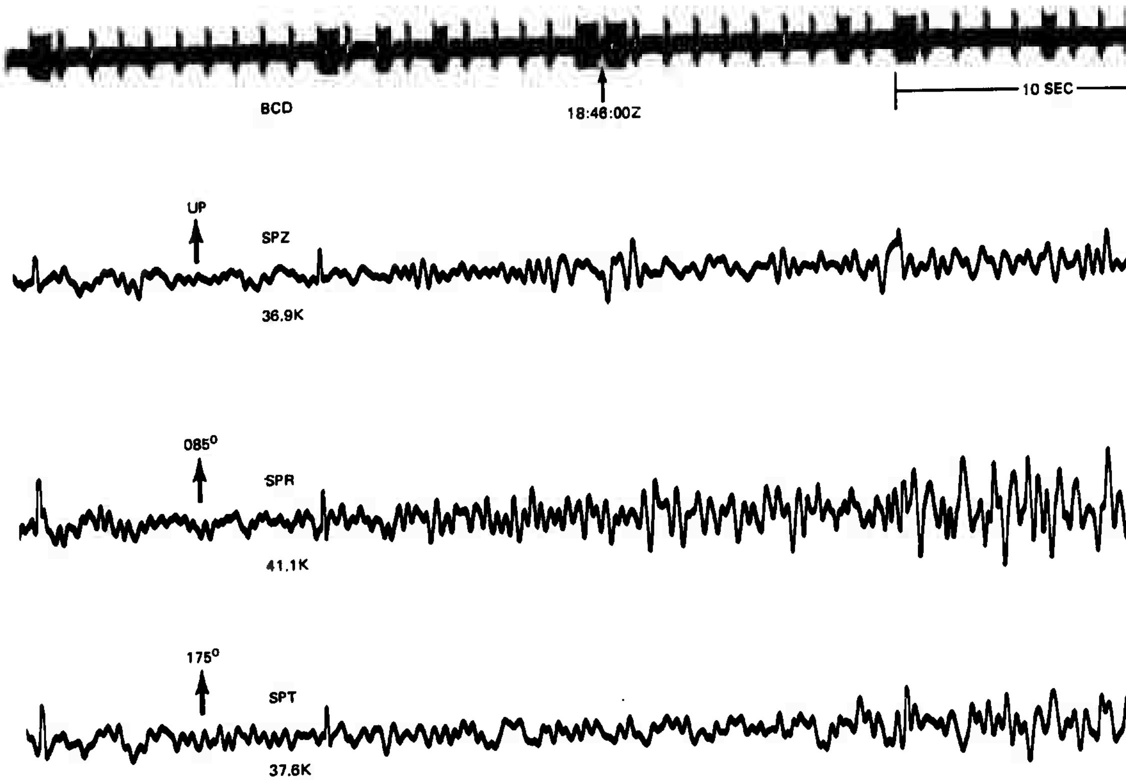


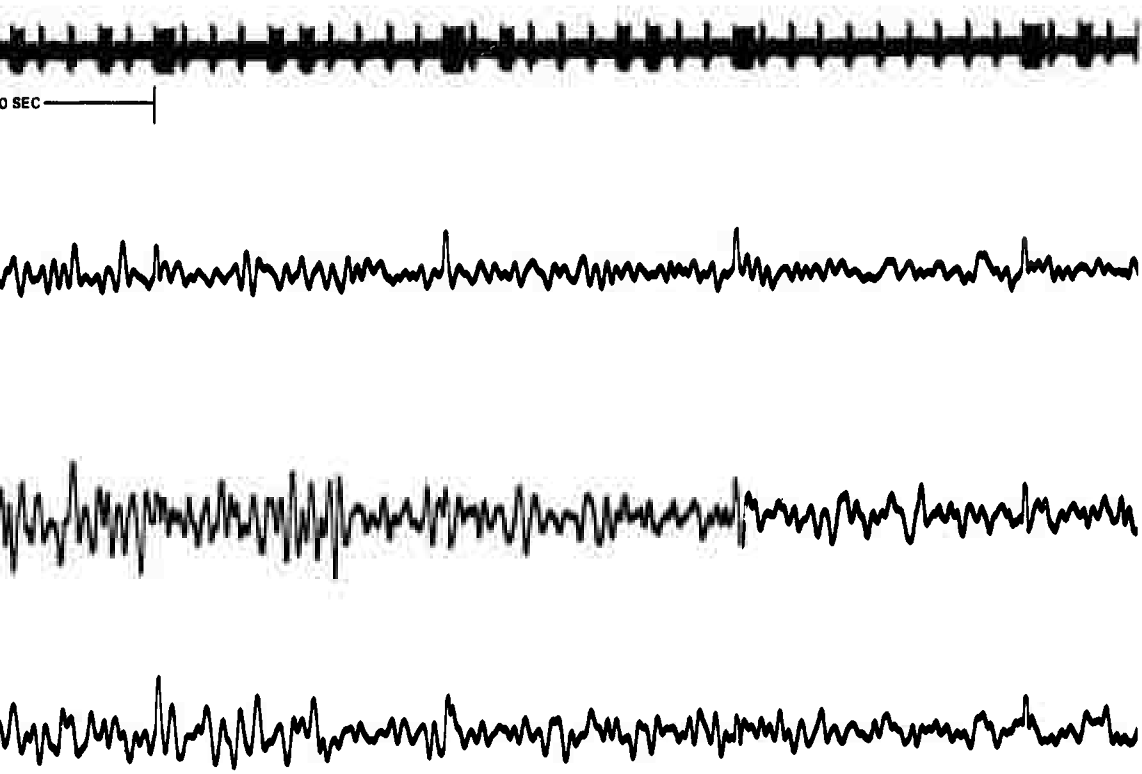

A




B

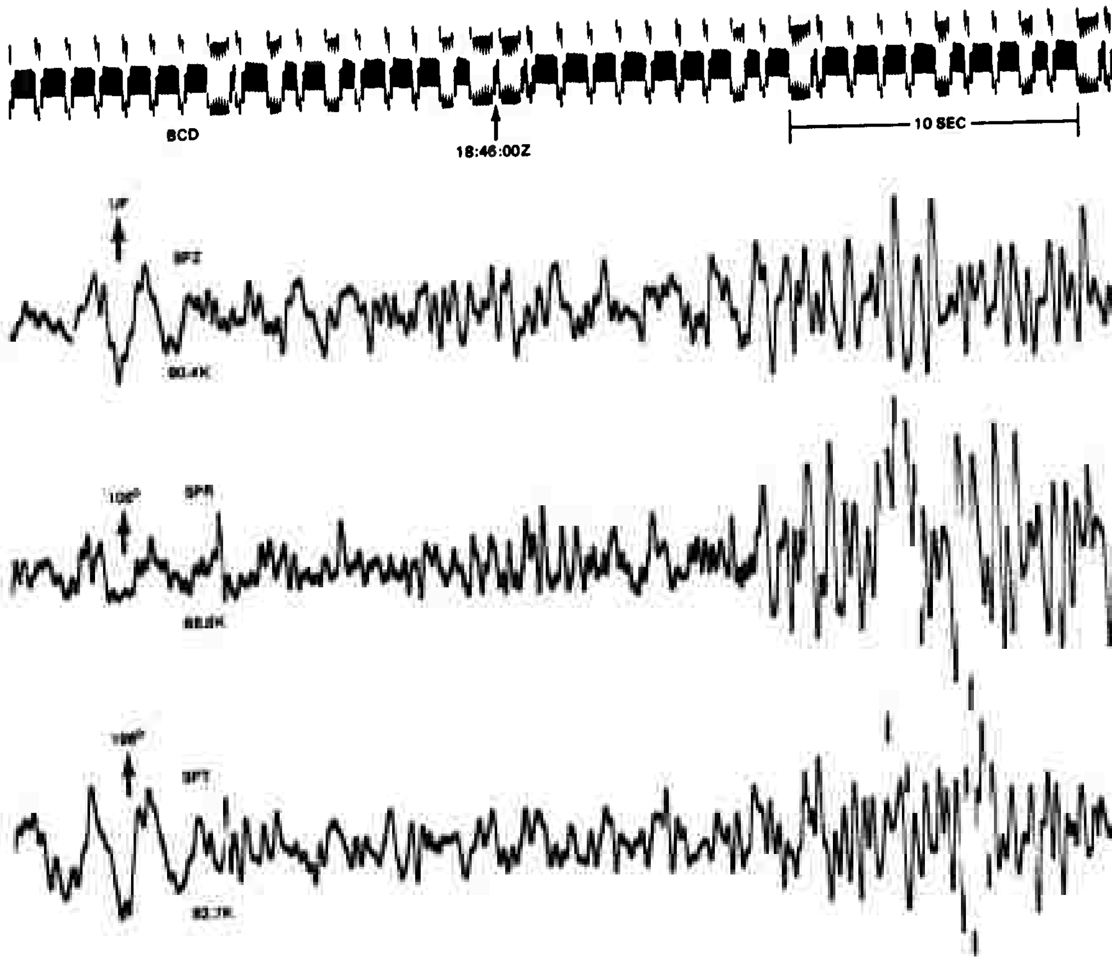
Figure 4. Site LL-MS, HUMID WATER event, 19 April 1970. Δ = 67.4 km. Magnification at 1.0 cps.


BCD
18:46:00Z
10 SEC
UP
SPZ
36.9K
085°
SPR
41.1K
175°
SPT
37.6K

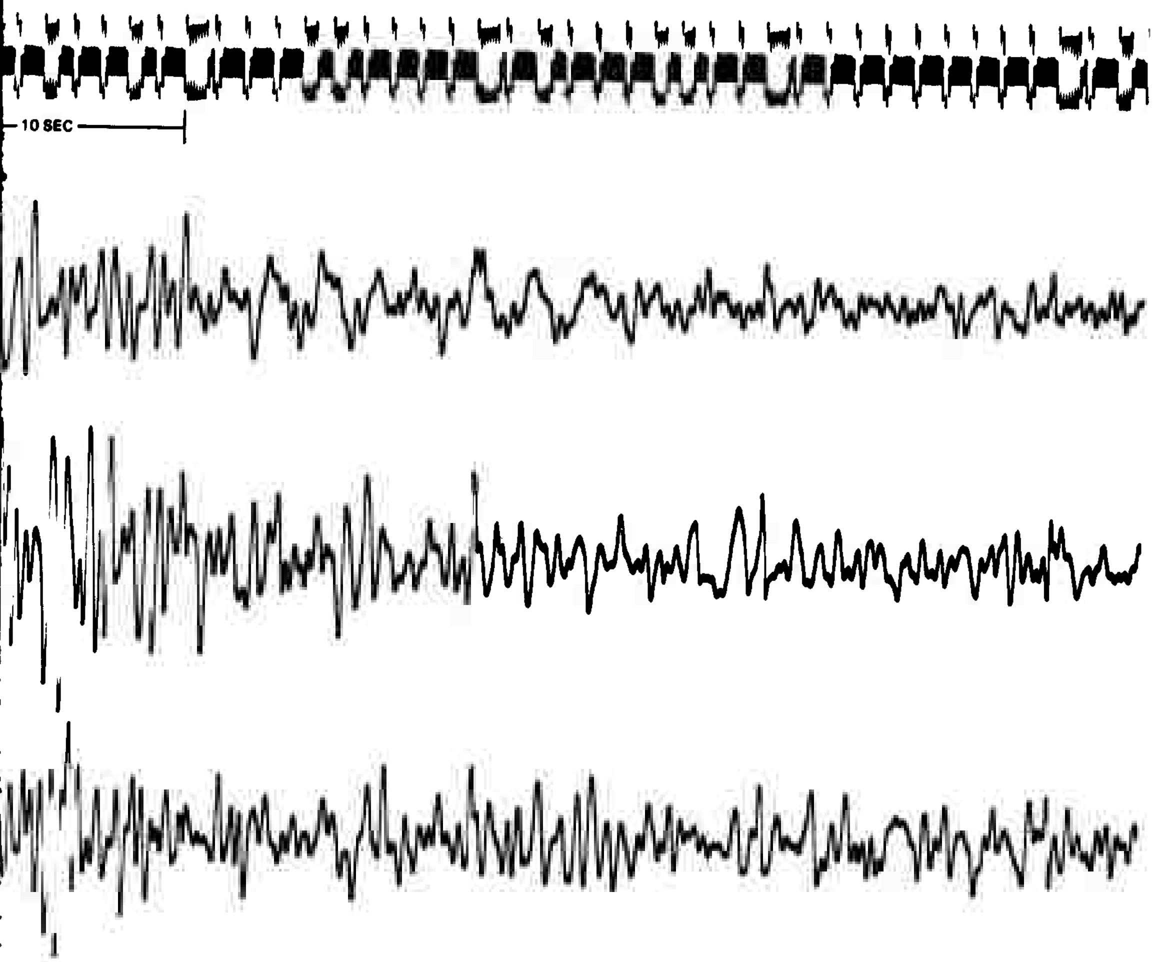



B

Figure 5. Site RI-MS, HUMID WATER event, 19 April 1970. Δ = 68.8 km. Magnification at 1.0 cps.

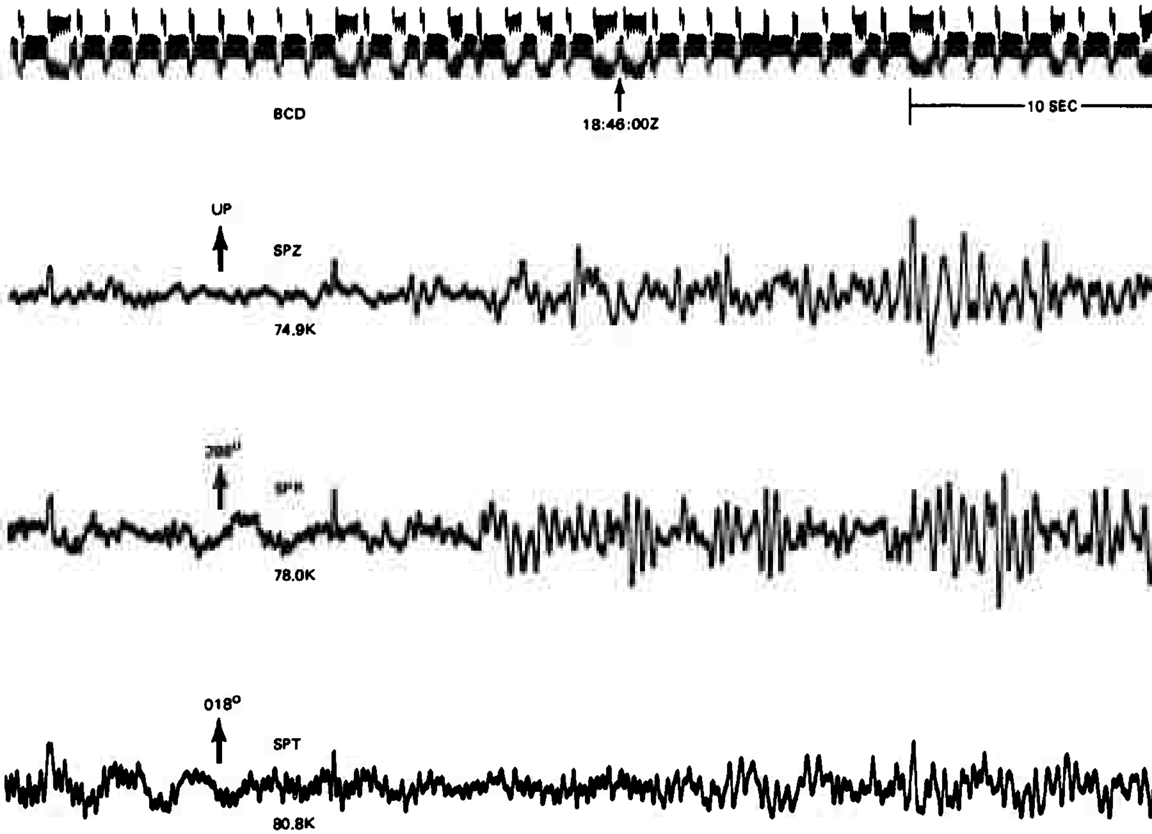



A

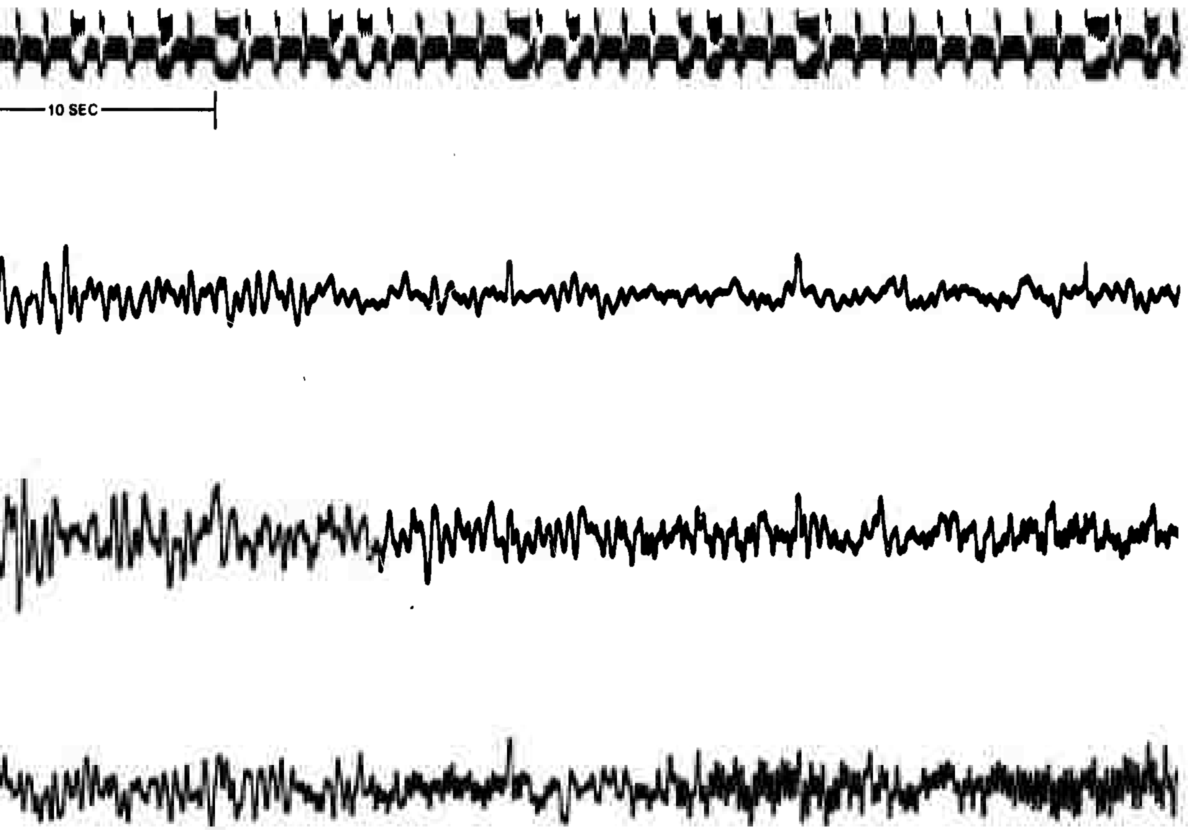



B

Figure 6. Site LD-MS, HUMID WATER event, 19 April 1970. Δ = 68.9 km. Magnification at 1.0 cps.

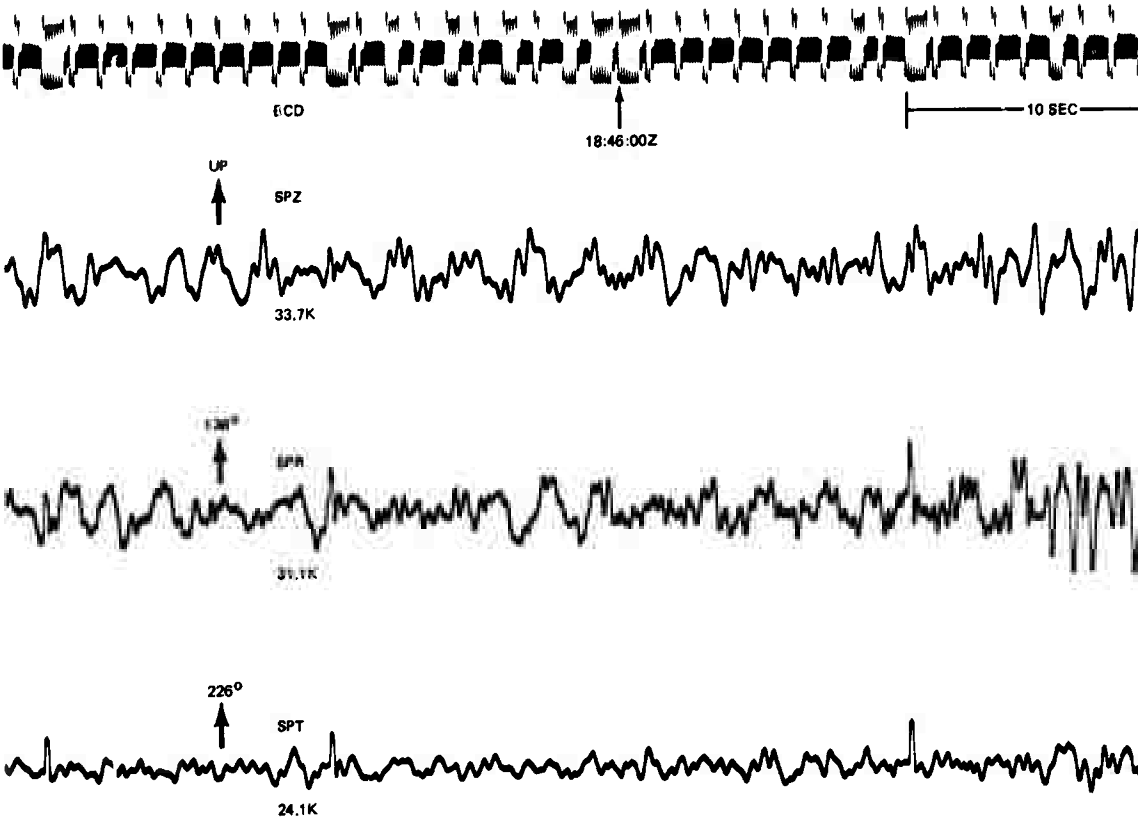



A




B

Figure 7. Site MB-MS, HUMID WATER event, 19 April 1970. Δ = 71.8 km. Magnification at 1.0 cps.




A

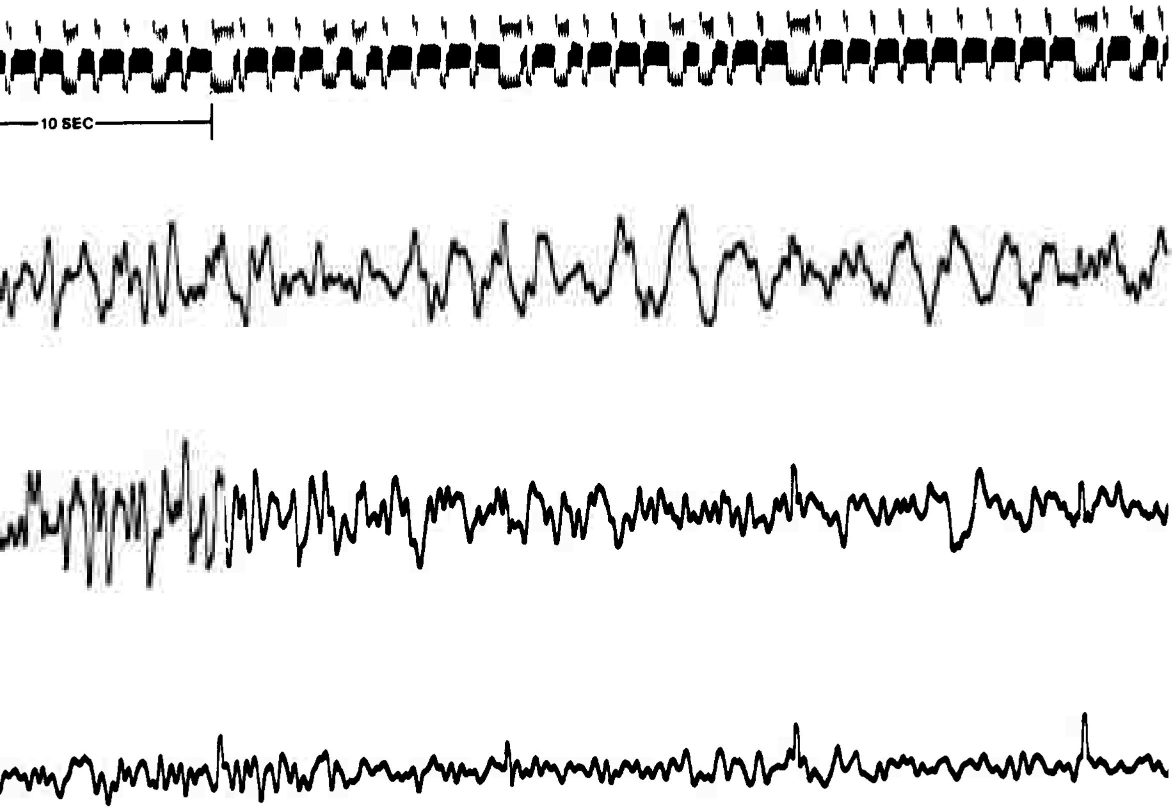
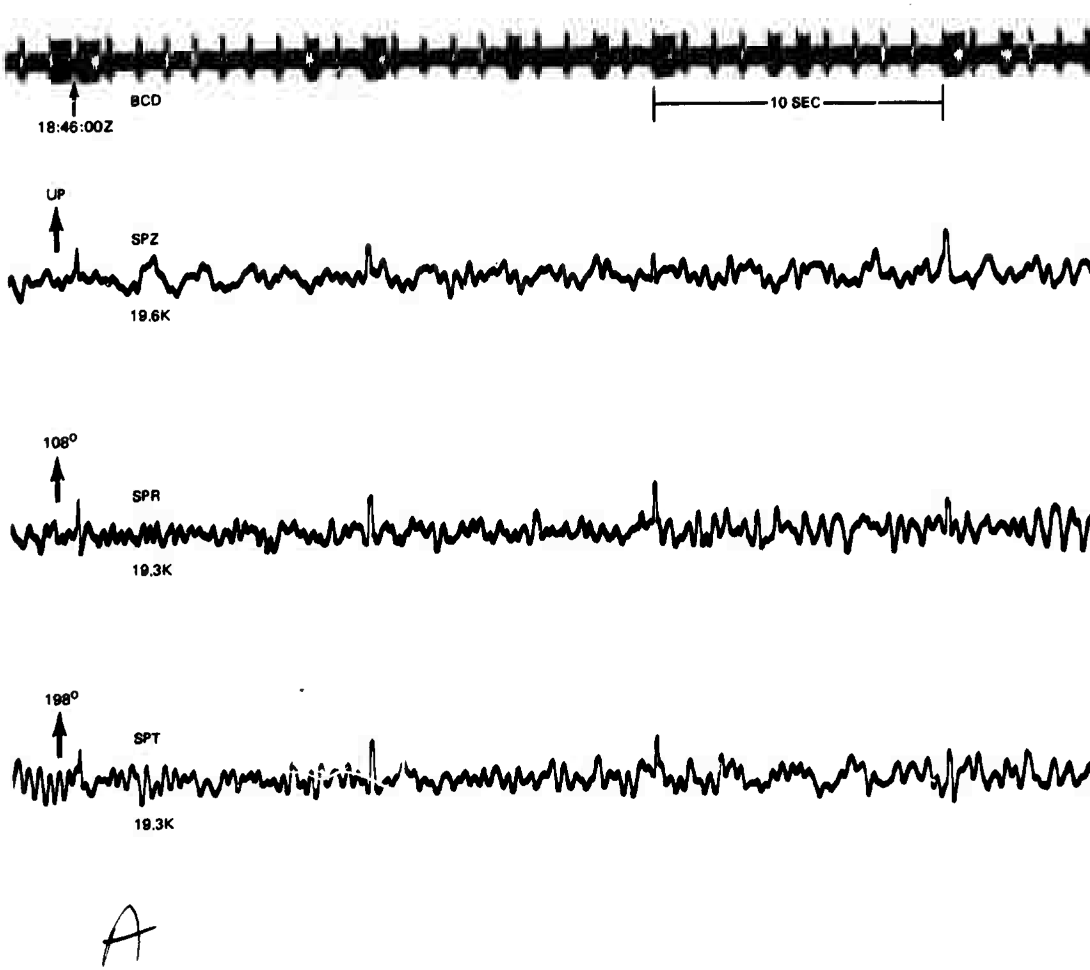



Figure 8. Site LD3MS, HUMID WATER event, 19 April 1970. Δ = 72.9 km. Magnification at 1.0 cps.


BCD
18:46:00Z
10 SEC
UP
SPZ
19.6K
108°
SPR
19.3K
198°
SPT
19.3K
A

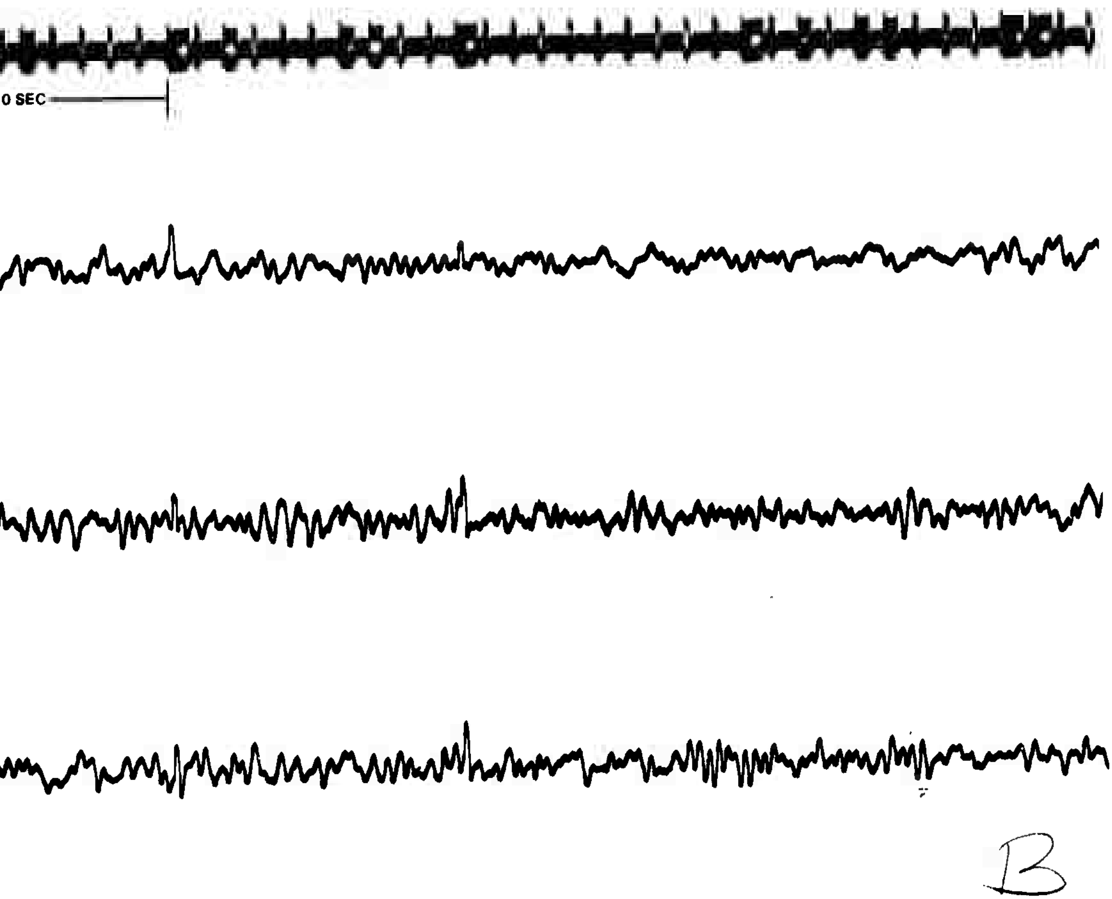



Figure 9. Site LD2MS, HUMID WATER event, 19 April 1970. Δ = 103.4 km. Magnification at 1.0 cps.

UNCLASSIFIED
Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Teledyne Geotech<br>Garland, Texas 75040 | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP |

3. REPORT TITLE

Preliminary report on Long-Range Seismic Measurements Participation in Project MIRACLE PLAY - HUMID WATER

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Data Report

5. AUTHOR(S) (First name, middle initial, last name)

Frank H. Johns

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| 18 May 1970 | 49 | 2 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br>F33657-70-C-0646 | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>Technical Report No. 70-16 |
| b. PROJECT NO.<br>VT/0703 | |
| c. | 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>None |
| d. | |

10. DISTRIBUTION STATEMENT

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, AFTAC.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES<br>None | 12. SPONSORING MILITARY ACTIVITY<br>Air Force Technical Applications Center |

13. ABSTRACT

The HUMID WATER gas explosion, the second of a series of experiments called Project MIRACLE PLAY, was monitored by eight LRSM portable systems teams. The teams occupied the same sites that were occupied for the DIODE TUBE explosion. Visual analysis of the seismograms shows that the STERLING, DIODE TUBE, and HUMID WATER signals were recorded at Lucedale, Mississippi (LD-MS). Spectra of the signals at LD-MS show that the power level of HUMID WATER was greater than that of STERLING.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| MIRACLE PLAY - HUMID WATER | | | | | | |
| Comparison with STERLING and DIODE TUBE | | | | | | |
| Tatum Salt Dome | | | | | | |